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ELEMENTARY PHYSICS

BY

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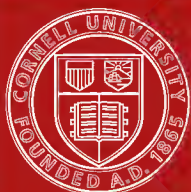
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PREFACE

THE method followed in this work is the same as that pursued in 'Sound, Light, and Heat' in this series; the leading facts are brought under the notice of the student by easy experiments, that do not demand expensive apparatus. Full instructions are given for the construction of the apparatus, in the text, or in the Appendix.

The work will serve as a suitable text-book for any class beginning the study of physics. The author believes that in early lessons it is inadvisable to trouble the student either with theories, or with the generalisations that prove such a valuable aid to the advanced student; little space has therefore been devoted to theoretical considerations. Experience as a teacher suggests that a careful examination of the facts of science is the first duty of a beginner.

Many illustrations are new, others are from 'Sound, Light, and Heat,' and from blocks in the possession of the publishers; several in magnetism and electricity are from Mr. Poyser's work on those subjects. Numerous easy examples will be found throughout the book.

M. R. W.

GATESHEAD : *October 1889.*

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H E A T



CHAPTER I

HEAT AND TEMPERATURE—THERMOMETERS

Heat and Temperature.—The earth is warmed by the heat from the sun. Savages ignite fires by rubbing together pieces of dry wood ; by rubbing a brass button upon a piece of wood, we can heat it sufficiently to render it unpleasant to the hand. When the brake is applied to a railway train, the friction heats the iron wheels, and sparks of molten metal fly from them. The blacksmith, by hammering a hot piece of metal, can raise it from a red to a white heat. Heat is supplied by the earth—notably by volcanoes, geysers, and hot springs. Heat is also generated by chemical action ; for example, the heat evolved when we pour water upon quicklime, and when we burn coal.

The principal sources of heat are, the sun, mechanical actions such as friction and percussion, the earth, and chemical action. Other sources will be mentioned in this volume.

We test the state of a body with respect to its heat by touching it, or by holding the hands near it. The laundry-maid determines when the iron is sufficiently hot, by holding it near her face. The nurse tests the state of the bath with respect to its heat by putting her hands in it.

The state a substance is in, with respect to the heat that affects the senses, is called its TEMPERATURE.

Our own sensations cannot be relied upon to give us exact knowledge of temperature. A warm day, when we are in good health, might be called a cold day if we were ill. A substance

we describe as warm to-day may be in a very different state, with respect to its heat, compared with the same substance that we described as warm yesterday. Two persons will not always agree concerning the temperature of a body : the glass-worker is not greatly distressed when the temperature of the factory in which he is working is unbearable to a visitor. Both hands will not always give the same verdict,—the right frequently feels cold to the left.

Plunge the right hand into hot water, the left into cold water ; after a minute plunge both into lukewarm water ; the right hand now feels cold and the left hand warm.

Touch pieces of iron, wood, and flannel, in a room shaded from the sun ; the iron feels cold, the wood fairly warm, and the flannel warm. We shall prove afterwards, that all are at the same temperature.

The hand may be a good measurer of temperature when confined to the same substance ; bath attendants are very expert in determining suitable temperatures of water for baths. We conclude, however, that generally the hand cannot be used for comparing the temperatures of bodies.

By mixing 1 lb. of hot water with 1 lb. of cold water, we obtain 2 lbs. of lukewarm water. The same amount of heat is there, but the temperature is different from either of the single pounds.

Temperature is a state or condition ; it is no more heat than the level of the water in a basin is the water itself. Heat is analogous to the water in a vessel ; temperature to the level of the water. Heat flows from a body at a high temperature to one at a low temperature, just as water flows from a high to a low level.

HEAT is the agent which produces the sensation of hotness, warmth, and similar sensations.

If a red-hot ball be placed in an exact balance, we can detect no change of weight when it cools, or loses heat. Heat, we infer, is not a material substance like water, that can be poured from one vessel to another. Remembering this, we may conveniently speak of heat flowing from a hot to a cold body, without regarding it as a material substance.

Expansion of Solids.—In nearly all cases a body expands when it is heated. The platelayer is instructed to leave a space between the ends of rails. A bridge is never fixed at both ends, one end being placed on rollers to allow for the change in length as the temperature changes. We can convince ourselves of the truth of the statement that bodies expand, when heated, by actual experiments.



FIG. 1.

A bar or rod of iron (fig. 1) about 18" long rests upon two blocks of hard wood; one end of the bar is held firmly by a heavy weight, the other end rests upon a sewing-needle; a light straw is fastened at right angles to the needle with sealing-wax, and a divided semicircle is fixed behind the straw. If the rod moves to the right or left, the needle will roll, and the pointer will move to the right or left. A very slight movement of the bar will cause a considerable movement of the index. Heat the bar with a spirit-lamp, the temperature rises, and the pointer informs us that the bar is expanding; on cooling, the pointer moves to the left, showing that the bar is contracting.

This experiment illustrates a bridge, one end fixed and the other upon rollers to allow for changes in the temperature.

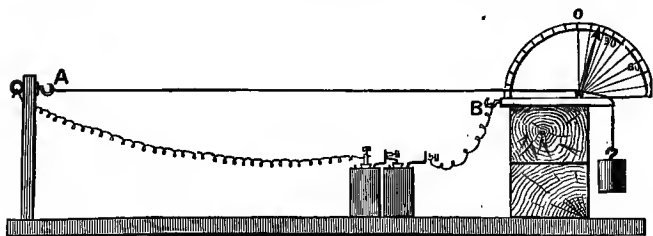


FIG. 2.

A more difficult experiment is the following:—A piece of platinum wire 18" long (fig. 2) is attached to an iron or copper

screw ; it passes over a piece of knitting-needle to which an index is attached as in the last experiment ; the wire then passes through a notch in the smooth iron bar upon which the needle rests, and is stretched by a pound weight ; the notch keeps the wire in position. If now one terminal of a pair of Grove's cells be attached to A, and the other terminal touch the iron bar B, a current flows through the wire, heats it, and the elongation is registered by the movement of the index. We may conveniently dispense with the Grove's cell, and merely run the flame of a Bunsen burner along the wire a few times. The heating makes the wire bend if both ends be fixed, but the bending is difficult to observe.

Telegraph wires "sag" more in summer than in winter, on account of expansion due to the weather, not to the electric current.

Expansion in length is called *linear expansion*.

A surface having length and breadth will expand in two directions. A window-pane, tightly fixed on a cold day, fractures on a warm day, if space has not been allowed for expansion.

A solid can expand in three directions ; such expansion is called *cubical expansion*.

Cut a hole in an iron plate so that a 4-oz. flask filled with cold water just passes. Fill the flask with hot water ; the area of the section of the flask increases, and the flask is unable to pass through the hole.

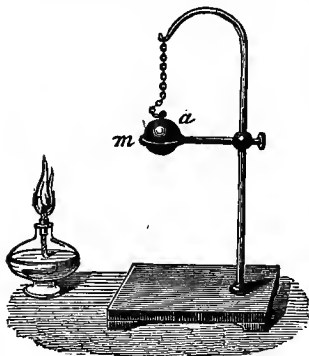


FIG. 3.

A historical experiment is Gravesande's Ring (fig. 3). A ball, *a*, passes the hole, *m*, when cold, but not when heated. Move the ball into different positions ; in no position will it pass ; the experiment, then, illustrates the cubical expansion of solids.

Expansion of liquids.—The illustration (fig. 4) represents a tube 12" long, inserted by a round cork into a 2-oz. flask. The flask is filled with water that has

been boiled (to expel the air) and coloured with red ink. A paper scale is fastened behind the tube. Place the flask in a dish of warm water; notice first a slight descent, then a steady rise of the liquid in the tube. The slight descent is due to the glass expanding before the heat is communicated to the water.

The expansion is readily observed, and we conclude that liquids expand much more than solids.

By fitting up similar flasks and filling them with various liquids, such as alcohol, turpentine, and mercury, we can compare the expansions of liquids. Move the corks, and arrange so that the liquids all stand at the same height. Place all in a dish of lukewarm water.

The alcohol expands most, turpentine second, water third, and the mercury the least. Observe that the mercury begins to move first.



FIG. 4.

EXAMPLES. I.

1. Define Heat and Temperature. Is temperature heat?
2. What is meant by expansion? When are the terms linear, square, and cubical expansion used?
3. How would it affect the rise of the liquid in fig. 4, if a tube be used (a) with a narrower bore (b) with a wider bore? What would be the effect of using a larger flask? Suppose the glass did not expand, how would this affect the rise of the liquid?



Thermometers.—A THERMOMETER is an instrument for measuring temperatures.

The expansion of solids is so small that they cannot be used for thermometers. Liquids, enclosed in glass tubes, make suitable thermometers. Mercury is preferred, although its expansion is not so marked as water and alcohol; it expands regularly, and remains a liquid at temperatures at which water and alcohol pass into vapour; it can be obtained pure, and as we saw in the last experiment, it takes the temperature of a body quicker than the other liquids. In the simple thermometers we have constructed, the bulbs are large and the tubes are open at the top. An open tube would admit dirt and allow

evaporation ; it would also allow the pressure of the atmosphere to affect the position of the liquid in the tube.

A Mercury Thermometer.—A small bulb is blown at the end of a tube with a fine uniform bore (fig. 5). A small bulb is chosen so that the mercury may quickly receive or lose heat, and a fine bore that for a slight change in temperature we may have a distinct motion of the mercury. A bulb is blown at the other end, and cut in two, so as to leave a small cup, A. Mercury is placed in the cup, but is unable to run through the fine bore. The tube is warmed, air is expelled, and on cooling, the mercury is forced into the bulb. This is repeated until the bulb and the tube are full. Finally the mercury is boiled, to expel all air and damp. The tube is next heated near the cup, drawn out, E, and cut off. The bulb is then placed in a bath of boiling oil, till the mercury oozes out at the point. When no more oozes out, a small flame is held to the point until the glass softens ; the flame is then removed from the bath, and the end of the tube closed, F. When the thermometer cools it contains only mercury and mercury vapour.

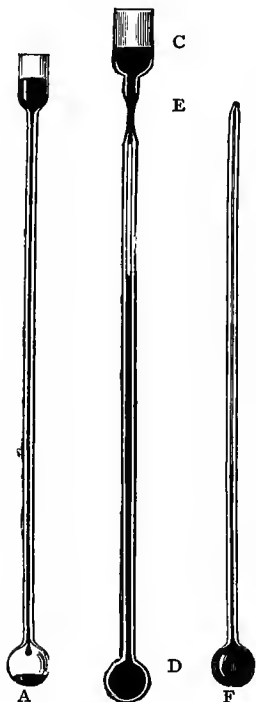


FIG. 5.

The fixed points.—A divided scale behind the tube might serve the purpose of one experimenter, but as different persons wish to compare temperatures, two fixed points have been agreed upon.

It is found that (1) the temperature of melting ice is always the same wherever or whenever the experiment is tried ; (2) that the steam of boiling water is always at the same temperature if the pressure be the same. The standard pressure in England

is taken as a pressure of 30 inches of mercury on the square inch, on the Continent as 760 millimetres of mercury on the square millimetre—that is, in England the barometer must either be standing at 30 inches, or allowance must be made for any variation.

I. THE FREEZING-POINT.—Clean snow or well-pounded ice is placed in a vessel (fig. 6). The thermometer is inserted, so that it is surrounded; it is left for a quarter of an hour and moved, until the thread of mercury is seen just above the ice; a scratch is then made with a file; this is the freezing-point. The water from the melted ice escapes at the bottom.

II. THE BOILING-POINT.—The bulb is placed in a metallic vessel (fig. 7), so

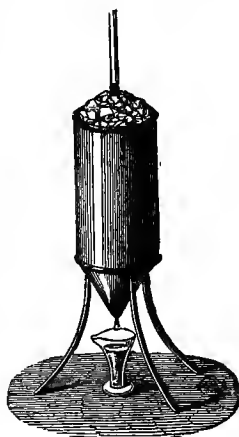


FIG. 6.

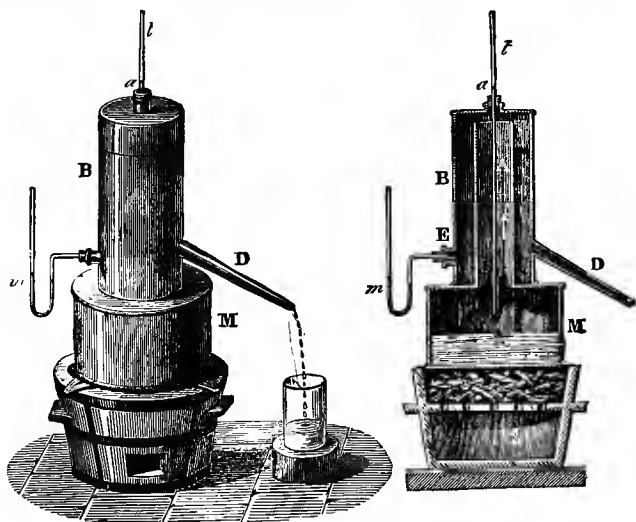


FIG. 7.

arranged that the tube is heated by steam. By following the

direction of the arrows it will be seen that the inner tube, A, is prevented from cooling by the steam surrounding it. The thermometer is moved until the mercury is just seen above the cork, *a*; when it is stationary a mark is made; this is called the boiling-point. If the barometer be not at 30 inches a correction is made from tables.

The Scale.—The distance between the fixed points is divided

into equal parts called degrees. Three methods are followed (fig. 8):

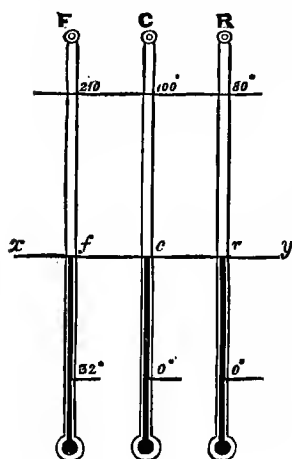


FIG. 8.

1. *Fahrenheit Scale.*—The freezing-point is marked 32 degrees (written 32°) the boiling-point 212° . Therefore the distance between is divided into 180 equal parts. This scale is in common use in England. Fahrenheit believed that his zero, 32° below freezing-point, was the lowest temperature experienced on the earth.

2. *Centigrade Scale.*—Freezing-point is 0° , boiling-point 100° . This scale is in common use on the Continent, and in general use for

scientific purposes.

3. *Reaumur's Scale.*—Freezing-point is 0° , boiling-point 80° . This scale is in common use in Germany.

The divisions are continued above and below the fixed points, the division below 0° being indicated as -1° , -10° , -15° , &c.

One hundred and eighty divisions on the Fahrenheit scale are equal to 100 divisions on the Centigrade. Therefore 9 divisions F. = 5 divisions C.

A thermometer reads 60° F. What is the reading on the Centigrade scale?

60° F. is $60 - 32$, or 28 divisions F. above freezing-point. That is $28 \times \frac{5}{9}$ C. divisions above freezing-point.

\therefore the reading is $28^{\circ} \times \frac{5}{9}$ or $15\frac{5}{9}^{\circ}$ C.

Change 12°C. into the Fahr. scale:—

12°Cent. above freezing-point = $\frac{12 \times 9}{5}$ or $21\frac{3}{5}$ divisions Fahr. above freezing-point. But as freezing-point is marked 32° on the Fahr. scale, the reading will be $(32 + 21\frac{3}{5})^{\circ} = 43\frac{3}{5}^{\circ}\text{Fahr.}$

Express 0°F. on the Centigrade scale.

0°F. is 32°Fahr. divisions below freezing-point.

$\therefore 32 \times \frac{5}{9}$ or $17\frac{2}{9}^{\circ}\text{C.}$ below freezing-point

\therefore the reading is $-17\frac{2}{9}^{\circ}\text{C.}$

EXAMPLES. M.

1. Define Heat and Temperature. What is meant by sensible heat?
2. What is a thermometer? Describe the construction of a mercurial thermometer.
3. How are the fixed points on the stem of a mercurial thermometer determined? Into how many parts is the distance between them divided on the Fahrenheit scale? To what temperature on the Centigrade scale does 179°F. correspond?
4. How many divisions of the Centigrade scale are equal to 54 divisions of the Fahrenheit scale on the same thermometer.
5. Change the following degrees Centigrade into degrees Fahrenheit: 50, 10, -7, 180, $32\cdot5$.
6. Express 90° , 30° , -15° , 32° , 180° Fahrenheit in the Centigrade scale.

Testing Thermometers.—Ordinary thermometers are rarely accurate; it will form a good exercise to test the thermometers which are in use in the class.

The apparatus for testing the freezing-point is readily made out of an ordinary tin, by punching a few holes in the bottom. It is important to use *clean* ice. After testing with clean ice, add a little salt, and test again. In a class experiment the thermometer indicated -10°C. when salt was added.

For verifying the boiling-point, a flask with a long neck and half-filled with water may be used (fig. 9). Pass a thermometer through a cork, through which also passes a bent open tube. The thermometer must not touch the water; it should merely be surrounded with the steam.

When the mercury is steady, add a little salt to the water, and note again the height of the mercury when immersed in the steam. Place the thermometer *in* the salt and water and observe the temperature; also in water containing calcium chloride.

EXAMPLE.

1. Freezing-point with clean ice = 0° C.
2. " " " ice and salt = -10° C.
3. Boiling-point with steam from water = 100.5° C. Error $.5^{\circ}$
4. " " " salt and water = 100.5° C.
5. " " " calcium chloride and water, the thermometer dipping into the water = 107° C.

Impurities affect the boiling-point of water, but do not affect the temperature of the steam from such water.

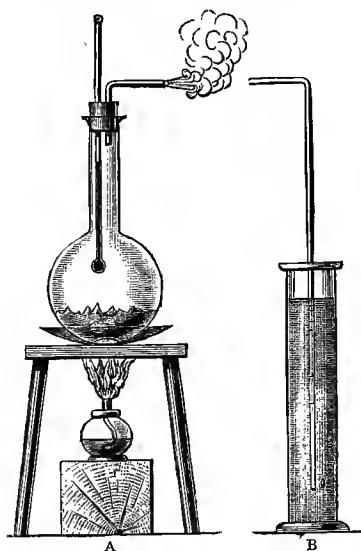


FIG. 9.

The mercurial thermometer can now be used to test the temperature of a body. Suppose it touches a piece of warm iron, heat flows from the iron to the mercury; the bulb being small the heat lost by the iron is inappreciable; soon the iron and the thermometer are at the same temperature, which is practically that of the piece of iron.

With the thermometer test the temperature of various bodies in the room. Show that all are at the same temperature. (See p. 2).

When the temperature is steady, the thermometer being surrounded by steam, connect the tubes of A and B with india-rubber tubing (fig. 9). The tube of B dips into water; therefore the steam has now to overcome a greater pressure; the mercury rises, showing that the temperature is rising. Let the tube of B dip into mercury; the steam has now to overcome a yet greater pressure, and a further increase of temperature is indicated.

The boiling-point depends upon the pressure the vapour has to overcome. In an experiment the thermometer, sur-

rounded by steam that escaped freely showed 101° ; when the tube dipped into 8'' of water the thermometer indicated 102° ; when mercury was substituted for water the boiling-point became 108° .

EXAMPLES. III.

1. Why should care be exercised in securing a tube of uniform bore?
2. What are the objections to constructing a mercury thermometer and leaving the top of the tube open?
3. How is a thermometer filled?
4. Why is it necessary to boil the mercury?
5. What is meant by 'the fixed points'? What precautions must be taken in obtaining the boiling-point?
6. Change the following degrees C. into F. : 15° , 30° , 17.5° , 0° , 100° , -30° , -10° . F. into C. : 180° , 212° , 70° , 60° , -12° .
7. How would you construct a water thermometer? How would you graduate it?
8. Explain how the fixed points on the stem of a mercurial thermometer are obtained. Why is it necessary, in marking the 'upper fixed point,' to take note of the height of the barometer?
9. How would you show that the boiling point changes as the pressure changes?
10. Does the thermometer measure heat? What does it measure?
11. Why is steam used rather than boiling water in determining the 'upper fixed point'?
12. What is meant by a 'degree' of heat, say 14 degrees Centigrade? What is meant by a change of temperature?

CHAPTER II

EXPANSION OF SOLIDS, LIQUIDS, AND GASES

The linear coefficient of expansion.—The general statement that solids expand when heated, is insufficient for practical purposes. We must know *how much* a given length of iron, say, will increase in length, when heated through a number of degrees. Small as the expansion is, it can be measured by methods, that are explained in advanced works.

A bar of iron measured 20'' at 0° C., and $20\frac{2}{100}$ '' at 100° C.

A brass rod at 15° C. was 24'' long; at 95° C. it was $24\frac{3}{100}$ '' long.

To compare the expansions of brass and iron, we calculate the elongation of each, when its temperature rises from 0° to 1° C., and compare the elongation with the original length. For all practical purposes we may calculate the elongation when the temperature rises one degree, beginning at any ordinary temperature. In the above example the elongation of the iron is $\frac{2''}{100}$ for 20'' when its temperature is raised 100° ∴ the elongation for 1° will be $\frac{2''}{100} \div 100 = \frac{2''}{10000}$. The relation between this elongation and the original length is $\frac{2''}{10000} \div 20'' = \frac{1}{100000}$.

The fraction $\frac{1}{100000}$ is called the linear coefficient of expansion of iron. Similarly we calculate that the linear coefficient of expansion of brass is $\frac{3''}{100} \div 80 \div 24'' = \frac{1}{64000}$.

THE LINEAR COEFFICIENT OF EXPANSION FOR ONE DEGREE, *is the ratio of the increase of length when the temperature is raised one degree, to the original length.*

TABLE OF COEFFICIENTS OF LINEAR EXPANSION for 1° C.

Glass	. = '0000085 = $\frac{1}{120000}$	Brass	. = '000016 = $\frac{1}{64000}$
Platinum	. = '0000085 = $\frac{1}{120000}$	Copper	. = '000017 = $\frac{1}{58000}$
Cast iron	. = '00001 = $\frac{1}{100000}$	Lead	. = '000028 = $\frac{1}{35000}$
Wrought iron	= '000012 = $\frac{1}{85000}$	Zinc	. = '00003 = $\frac{1}{34000}$

This table is only approximate as different specimens vary in their expansions. It assumes that the expansion from 0° to 1° C. is $\frac{1}{100}$ of the expansion from 0° to 100°; this is nearly true, and it is by measuring the expansion for 100°, or some such range of temperature, that the coefficient is determined. The coefficient for 1° F. will be $\frac{5}{9}$ of the above values.

The coefficient of cubical expansion is three times the coefficient for linear expansion.

This will be understood by considering fig. 10. Let the thick lines represent a cube of one foot side, that increases *very slightly* in three directions; let its coefficient of linear expansion be '001.

The increase in volume will be three slabs (A_1 , A_2 , and A_3 are the diagonals), three strips (a section of each is shown), and a small cube. The strips and cube will be so small compared with the original volume *when the expansion is very small*, that they may be neglected. The increase in volume will therefore practically be the volume of the three slabs. And the coefficient of cubical expansion (increase in volume \div original volume) will be '003 c. ft. \div 1 c. ft. = '003. That is, three times the coefficient of linear expansion.

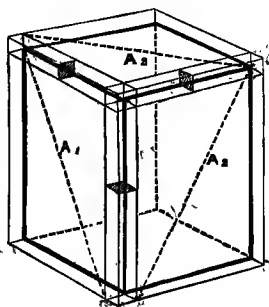


FIG. 10.

EXAMPLES. IV.

1. Find the coefficient of expansion in the following examples:—

a. A rod of brass at 15° C. measures 2 feet; at 95° C. it measures 2.003 feet.

b. A rod of glass at 10° C. measures 5 feet; at 70° C. it measures 5.0024 feet.

2. Explain what you mean when you say that the coefficient of linear expansion of iron is 0.000012. If an iron yard-measure be correct at the temperature of melting ice, what will be its error at the temperature of boiling water?

3. From London to Edinburgh is 400 miles. Suppose the hottest day in summer to be 90° F. above the coldest day in winter; find the difference in length in the rails laid on the railway between the two places.

4. A rod of brass just fits between two supports; ice-cold water is poured over it and the bar falls. Why is this? The bar is now heated in a boiler and is found to be too long. Why?

5. A rod of lead, 6 feet long, was fixed between two firm supports on a day in winter. It was examined in summer and was found bent. Explain why.

Forces of Expansion and of Contraction.—Solids in expanding and contracting do work.

A B (fig. 11) is an iron bar passing through sockets in a strong cast-iron frame, CD. The iron bar has a hole at one end, through

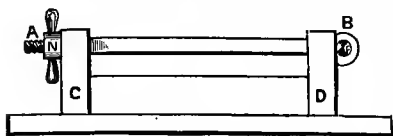


FIG. 11.

which passes a small rod, F, of cast iron. At the other end is a screw-thread, A, on which a nut, N, with two arms works. The rod is heated, placed in its sockets, the rod F is

inserted, and the nut screwed up tightly. As the temperature falls, the bar contracts, and the force is sufficient to break the rod of cast iron F.

The force exerted is enormous; an iron rod 1 square inch in section in cooling through 9° C. exerts a force of 1 ton.

A striking illustration is afforded in the case of telegraph wires. An iron wire stretched across a span of 400 feet with a sag of 5 feet at a temperature of 25° C. would have a strain upon it of 13,544 lbs. per square inch. In winter, at a temperature of -5° C. the strain would be 34,000 lbs. per square

inch, sufficient to permanently stretch the wire. The iron tyres of wheels are placed on red-hot and fit loosely; on cooling they secure the woodwork tightly.

Effects of expansion and contraction.—Draw out a piece of glass tubing; cut the end off, leaving a small hole; insert a piece of platinum wire and heat in the flame. The glass fuses, the hole closes, and on cooling the platinum is found to be firmly imbedded. Try the same experiment with an iron wire—either the glass cracks, or the hole is not closed.

The coefficients of expansion of glass and platinum (p. 13) are equal, while there is a marked difference between the expansion of glass and iron.

Solder a strip of brass and a strip of iron together, hammer them until they are straight; heat the compound bar; it bends, the iron being on the concave side.

The coefficient of expansion of brass is $\cdot 000016$; that of iron = $\cdot 00001$. The brass expands more than the iron, and therefore forms the convex side of the bend.

The rate of a chronometer depends upon the mass of the balance-wheel (fig. 12), and the distance of the circumference from the centre. The parts *BC* are made up of a compound strip like the above, the metal having the highest coefficient of expansion being on the outside. When heated the radius *A* expands, and the chronometer would lose time; but the heat also causes the strips *BC* to curve inwards, the masses *D* are thus brought nearer the centre, and this compensates for the extension of *A*.

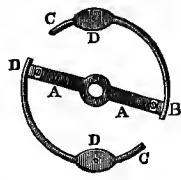


FIG. 12.

Compensating Pendulums.—Any alteration in the length of the pendulum affects the time of the clock. Pendulums so constructed that they do not alter their number of swings per second as the temperature changes, are called compensating pendulums.

In Harrison's gridiron pendulum (fig. 13) *a, b, c, d* are rods of steel; *h, k* are brass. If the temperature rise, *a, b, c, d* expand and force the 'bob' farther from the point of suspension; *h* and *k*, in

expanding, lift the crosspiece n, m , and thus lift the 'bob.' The rod d passes freely through a hole in ro . The lengths are so arranged that h, k compensate the effect of a, b, c, d .

The coefficient of linear expansion of brass to that of steel, is roughly 'as 5 to 3. The length $a + b + d$ should be to h as 5 is to 3.

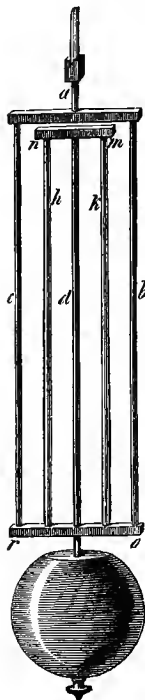


FIG. 13.

EXAMPLES. V.

1. Make a table for the coefficients of cubical expansion from the table on page 13.
2. A glass vessel contains 120 cubic inches at 0° . Find its volume at 100° C.
3. Water-pipes are fitted by telescopic joints. Why?
4. What would be the effect of fixing firmly the ends of furnace-bars?
5. A glass bottle holds, when quite full, at the temperature of melting ice, 20 cubic inches of ice-cold water. How many cubic inches of boiling water will it hold, the bottle as well as the water being at 100° C.? (Coefficient of linear expansion of glass = '000009).
6. Telegraph wires sag more in summer than in winter. Why? Suppose the distance between two posts to be 80 yards and the wire to be made of copper, what change would there be in the length when the thermometer rose from 0° C. to 20° C.?
7. How would you prove that zinc expands more than copper when rods of the two metals are heated through the same range of temperature?

Expansion of Water.—We have already seen that liquids expand when the temperature rises, and contract when the temperature falls; the expansion observed is not, however, the real expansion, as the glass covering also expands. If the glass did not expand, the expansion of the liquid would be greater than that observed in the experiment. The real expansion is found by adding the apparent expansion of the liquid to the expansion of the glass.

Fill the flask in fig. 4 with water, insert the cork and apply heat until the water runs out at the top. Now place the flask in clean melting ice (what is the temperature?) and observe carefully the movement of the liquid in the tube. There is a gradual descent, followed by a slight ascent, and ultimately it comes to rest.

Remove the flask from the ice, the temperature rises, and the liquid in the tube first contracts and then expands. The meaning evidently is, that water in cooling down to a certain temperature near 0° C. contracts, and that if the temperature fall further it then expands. Repeat the experiment after placing a thermometer through the cork of the flask; observe the temperature, when the volume is least, will be 4° C. or 39.2° F.

Thus a cubic inch of water weighs more at 4° C. than a cubic inch at any other temperature. The mass of a unit

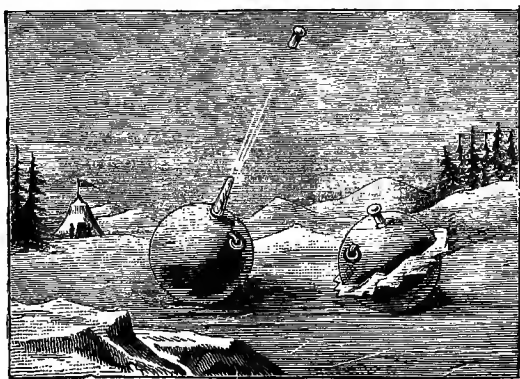


FIG. 14.

volume is called the density of a substance. The density of water is greatest at 4° C. or 39.2° F. Liquids generally do not act like water, they expand gradually from their freezing-point.

Ice floats in water; the density of ice must, therefore, be less than that of water. That is, water expands on freezing.

Solid paraffin sinks when thrown into melted paraffin—that is, paraffin contracts when it passes from the liquid to the solid state. Iron acts in a similar manner.

Fill the flask (fig. 4) with ice and water, and insert the cork. As the ice melts, the water sinks in the tube, proving that water occupies less volume than an equal mass of ice.

Blow a small bulb in the end of a glass tube; fill the tube with cold water and seal it: put it in a mixture of ice and salt (temperature below 0° C.); the water freezes, expands, and bursts the tube.

Place a similarly sealed bulb in warm water. The water in the tube expands, and it again bursts.

The great force exerted when water expands in changing into ice, is illustrated by the experiments of Major Williams in Canada. He filled iron bomb-shells with water, closed the holes firmly with iron plugs, and exposed the shells to the frost. In one experiment the plug was forced out, a loud report was heard, and a cylinder of ice was forced through the hole. In a second experiment the stopper remained, but the shell was cracked, and a cylinder of ice forced its way through the crack (fig. 14). Water in the crevices of rocks freezes in winter, expands, and exerts force sufficient to split the rocks.

Results of the peculiar expansion of water.—In winter the surfaces of ponds and lakes lose heat. The surface water being, bulk for bulk, heavier than that below, sinks ; this goes on until the whole pond is at 4° C. The surface water cools, but it is now less dense than the water below ; it therefore floats, its temperature falls until it freezes, and the ice, as we know, floats. If water were like paraffin, the surface water would, down to freezing-point, be heavier than the deeper water ; thus the whole pond would be reduced to 0° C., a temperature that would destroy much of the animal life that now exists at 4° C. If the water on freezing continued to contract, layer after layer of ice would sink to the bottom until the whole pond would be a mass of ice, that the heat of summer would be unable to melt.

EXAMPLES. VI.

1. A pond is just about to freeze. Will the surface water or the water at the bottom be the warmer ? Why ?
2. Describe what takes place when a cubic foot of water is cooled down from 30° C. to 0° C. Give a diagram of it at its most important temperatures.
3. Describe a method of showing the unequal linear expansions of solids by heat. Explain how this unequal expansion is made use of in the gridiron pendulum.
4. The rim of the balance-wheel of a watch is made up of rings of two different metals, one outside the other, and is cut at two points ; explain

how it is possible for the rate of the watch to be the same in hot and cold weather.

5. Two iron bottles are filled with water at 4°C . and plugged. One is placed in warm water, the other in a mixture of ice and salt. What takes place in both cases? Why?

6. Explain how you would construct a seconds pendulum which will keep correct time in hot or cold weather.

7. Describe a gridiron pendulum made of zinc and iron bars. What must be the ratio between the lengths of the bars of the two metals? and why?

8. Water is said to have its maximum density at 4°C . Explain what this means.

9. In what respect is the behaviour of mercury different from that of water, when both are gradually warmed from 0°C .?

Expansion of gases.—Gases expand in volume when heated, much more than solids or liquids.

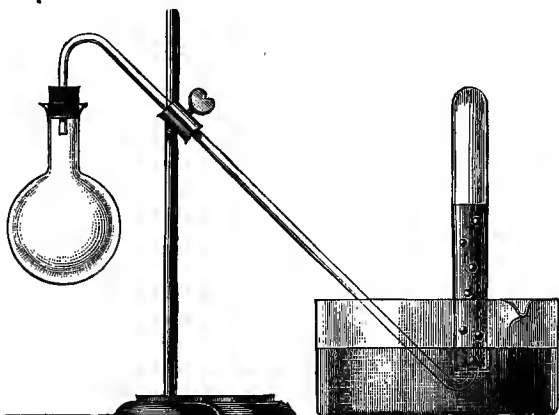


FIG. 15.

Insert a tube bent as in fig. 15 in a 2-oz. flask; clamp the apparatus so that the end of the tube dips under water. Fill a test-tube with water, and invert it over the end. The heat of the hand clasp- ing the flask is sufficient to cause expansion of the air in the flask, and part is forced into the test-tube. Remove the hand; as the air cools, water rises in the tube. Heat from a flame shows this in a more marked degree.

A simple air thermometer.—Fit up a piece of apparatus like

fig. 4, but do not place any liquid in the flask. Invert, and dip the end of the tube into a glass containing coloured water. Warm the flask so as to expel a little air. On cooling, the coloured water rises in the tube, and its movements show the effect of change of temperature upon the confined air (fig. 16).

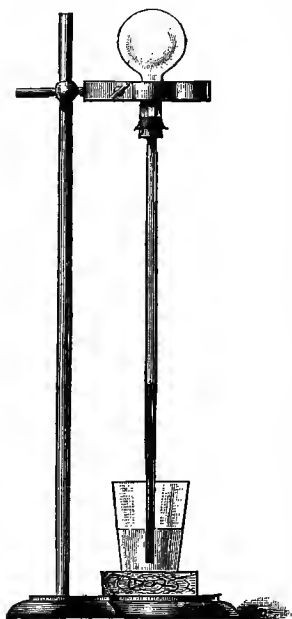


FIG. 16.

This apparatus forms the simple air-thermometer ; it can be graduated by attaching a scale, and noting the position of the liquid at two temperatures, as shown by a mercurial thermometer. The air-thermometer is not so convenient as an ordinary thermometer, but it is much more sensitive.

The expansion for all ordinary gases is the same.—Place side by side two flasks, with tubes, each constructed as in fig. 15. Fill one with coal-gas, the other with air. Put a dish of warm water underneath them, raise it, so that the water surrounds both flasks to the same height. The quantity of coal-gas and air collected in the two test-tubes will be almost equal.

Equal volumes of air and coal-gas are raised through the same temperature, and the expansions are equal. If we substitute hydrogen, oxygen, or any ordinary gas for air and coal-gas, and heat the flasks to the same temperature as before, we shall again find that the same amount of gas is expelled. We conclude that the expansion of all ordinary gases is the same.

Careful measurements have shown that 273 cubic inches of a gas at 0° C. become $273 + 1$ cubic inches at 1° C. ; $273 + 10$ at 10° C. ; $273 + 50$ at 50° C. ; and $273 - 5$ at -5° C. ; or 491 cubic inches at 32° F. become $491 + 5$ at 37° F. ; and $491 - 20$ at 12° F.

Leslie's Differential Thermometer.—Fit two 2-oz. flasks each

with a good cork, each cork having two holes. Bend a piece of glass tubing 24" long as in fig. 17; draw coloured water into the bend, and insert the tube in the corks. Place a glass stopper in each of the other holes; by using these stoppers arrange that the liquid stands the same height in each limb. Fasten the thermometer to a board. If one bulb be warmed more than the other, the index of coloured water moves.

This thermometer shows difference of temperature, and is very sensitive.

EXAMPLES. VII.

1. How would you show that a gas (air for example) expands more than a liquid (water)?

2. Describe an air thermometer. What are its advantages and disadvantages compared with an ordinary thermometer?

3. At 0°C . the volume of a certain mass of air is 1,092 cubic feet, what will be the volume at 20°C ., 100°C ., and -20°C .?

4. How would you show that the expansion of air and coal-gas are nearly equal?

5. Define the coefficient of linear expansion. How do you obtain the coefficient of cubical expansion from it?

6. Is a cubic foot of air at 0°C . heavier or lighter than a cubic foot at 100°C .? Give reasons for your answer, and explain how you would prove it by experiment.

7. Describe Leslie's differential thermometer.

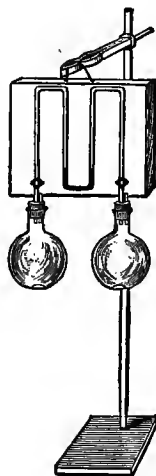


FIG. 17.

CHAPTER III

HEAT AS A QUANTITY. SPECIFIC HEAT

The thermal unit.—The previous experiments have shown, that heat is something that flows from a body at any temperature, to a body at a lower temperature, analogous to a flow of water from a high to a lower level. It does not mean that heat is a material substance, like water ; in fact, all experiments are against such a statement. A body weighs no more when hot than it does when cold ; we cannot isolate heat or regard it as a distinct substance. In order to measure heat it is necessary to select a unit, the selection of the heat-unit is based upon the following and similar experiments :—

Provide two beakers, and weigh into each, one pound of water. It is convenient to have the water in one beaker at 0° C. ; this is readily obtained by making up the weight with a few pieces of ice ; when the ice has completely melted, the temperature, noted by the thermometer, will be found to be 0° C. Test with the thermometer the temperature of the water in the second beaker ; suppose it to be 16° C. Now mix the contents of the beakers ; we shall have two pounds of water at 8° C. The heat given up by 1 lb. of water cooling from 16° to 8° has been sufficient to raise the temperature of 1 lb. from 0° to 8° . Weigh again 1 lb. of water into each beaker, and warm the water in one of them. Note the temperature of each, mix, and note the resultant temperature.

One pound of water at 16° C. + 1 lb of water at 40° C., = 2 lbs. of water at 28° C. That is, 1 lb. of water in cooling (from 40° C. to 28° C.) through 12° , raises the temperature of 1 lb. 12° (from 16° C. to 28° C.).

Generally, the heat given up by 1 lb. of water in cooling 1° , is equal to the heat required to raise 1 lb. of water 1° . We infer, and can verify by experiment, that it requires 15 times

as much heat to raise 3 lbs. of water 5° as it does to raise 1 lb. of water through 1° .

The amount of heat required to raise the temperature of 1 lb. of water from 0° C. to 1° C. is called the THERMAL UNIT.

The French define their unit by using 1 gram as the unit of mass; workmen use 1 lb. as the unit of mass, and 1° F. The reason 'from 0° to 1° ' is inserted is, that the amount of heat required to raise 1 lb. from 60° to 61° , say, is not exactly equal to the heat required to raise 1 lb. from 0° to 1° . The difference is, however, very small, and can practically be neglected.

Capacity for Heat.—Roll a strip of lead weighing 1 lb. into a spiral, hang it by a thread, in a beaker containing 1 lb. of water (fig. 18). Heat the water to boiling (what will its temperature be nearly? Test it with a thermometer). Provide two other beakers, each containing 1 lb. of water at the temperature of the room, say 16° C. Remove the lead at 100° , and place it in one of the beakers of water. Then pour the pound of water at 100° into the other pound of water at 16° . Stir and note the temperatures. In the above experiment, the temperature of the lead and water after mixing was $18\frac{1}{2}^{\circ}$ C., and that of the 2 lbs. of water 58° .



FIG. 18

One pound of lead cooling through $81\frac{1}{2}^{\circ}$ (100 to $18\frac{1}{2}$) raises 1 lb. of water $2\frac{1}{2}^{\circ}$ (16 to $18\frac{1}{2}$).

One pound of water cooling 42° (100° to 58°) raises 1 lb. of water 42° (16 to 58).

1 lb of lead cooling $81\frac{1}{2}^{\circ}$ raises 1 lb. of water $2\frac{1}{2}^{\circ}$

\therefore 1 lb. " " $\frac{81\frac{1}{2}^{\circ}}{2\frac{1}{2}^{\circ}}$ " " 1°

i.e. 1 lb. " " $36\frac{1}{2}^{\circ}$ " " 1°

and we conclude that one thermal unit raises 1 lb. of lead $36\frac{1}{2}^{\circ}$

Therefore to raise 1 lb. of lead 1° requires $\frac{1}{36\frac{1}{2}}$, or nearly $\frac{1}{73}$ thermal units.

The number of thermal units required to raise 1 lb. of a

substance one degree of temperature, is called the CAPACITY FOR HEAT of that substance.

Perform a similar experiment with 1 lb. of iron. The iron heated to 100 C. was placed in water at 16° C. ; the resultant temperature was 24½° C.

1 lb. of iron cooling $(100 - 24\frac{1}{2})^\circ$ C. heats 1 lb. of water $(24\frac{1}{2} - 16)^\circ$ C.

∴ 1 lb. of iron cooling $75\frac{1}{2}^\circ$ heats 1 lb. of water 1°

∴ 1 lb. „ „ 9° (nearly) „ „ 1°

We conclude that to raise 1 lb. of iron 1° requires ⅙ thermal unit, and the capacity for heat of iron is ⅙ units.

Now heat 1 lb. of water to 100°, the iron being at the temperature of the room (16°). After mixing the temperature is 91½°. This shows strikingly that the capacity for heat of iron is much less than that of water.

1 lb. of water cooling 8½° heats 1 lb. of iron 75½°

∴ 1 lb. „ „ 1° „ „ 9° (nearly)

Other experiments show that the heat required to raise 1 lb. of water through 1° will raise through 1° 10½ lbs. of zinc, 11 lbs. of copper, 16 lbs. of silver, or 5½ lbs. of glass ; and the respective capacities for heat are there-

fore $\frac{2}{21}$, $\frac{1}{11}$, $\frac{1}{16}$ and $\frac{2}{11}$ units.

Put 30 grams of white beeswax in a saucer half-full of water and place all in an oven until the wax is melted ; allow it to cool. When it first solidifies cut round the edges. Let it stand for a day to harden ; remove the wax and place it on a large ring of a retort-stand. Suspend cylinders of lead, bismuth, copper, and iron by a fine wire for

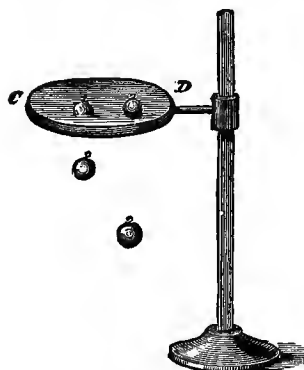


FIG. 19

some time in boiling oil. Remove and place them on the wax plate. The iron melting the wax, falls through first, followed by the copper ; lead and bismuth are unable to struggle through (fig. 19).

The rate at which the cylinders pass through depends on (1) their density, (2) the amount of heat they give to the wax. Compare copper and lead. The lead is the heavier and has this advantage over the copper; the copper, therefore, must give up a greater amount of heat in cooling; its capacity for heat is higher. The experiment cannot, however, for these reasons be used to compare accurately the capacity for heat of bodies.

Specific Heat.—THE SPECIFIC HEAT of a body, is the ratio of the quantity of heat required to raise that body one degree, to the quantity required to raise an equal mass of water one degree.

The specific heat is therefore the capacity for heat of the substance, divided by the capacity for heat of water. The specific heat of lead is $\cdot 03 \text{ unit} \div 1 \text{ unit} = \cdot 03$; that of iron $\frac{1}{9} \text{ unit} \div 1 \text{ unit} = \frac{1}{9}$. (See p. 24.) Calculate the specific heats of the bodies whose capacities for heat are given above.

Weigh 1 lb. of mercury into a test-tube; place the tube in boiling water; after some time the mercury will be at 100° . Pour the heated mercury into $\frac{1}{2}$ lb. of water at 17° C. say, stir thoroughly and note the final temperature; it will be about 22° .

1 lb. of mercury cooling 78° raises the temperature of $\frac{1}{2}$ lb. of water 5° .

\therefore 1 lb. of mercury cooling 78° raises the temperature of 1 lb. of water $2\frac{1}{2}^{\circ}$.

\therefore 1 lb. of mercury cooling $\frac{78^{\circ}}{2\frac{1}{2}}$ raises the temperature of 1 lb. of water 1° .

i.e. the heat required to raise the temperature of 1 lb. of water 1° raises the temperature of 1 lb. of mercury through 31° . The capacity for heat of mercury is $\frac{1}{31}$ unit, as found by the experiment; more accurately it is $\frac{1}{30}$ unit. Its specific heat is $\frac{1}{30} \text{ unit} \div 1 \text{ unit} = \frac{1}{30}$. A similar experiment shows that the specific heat of turpentine is about $\frac{2}{5}$.

One unit of heat will raise 30 lbs. of mercury 1° , and $2\frac{1}{2}$ lbs. of turpentine 1° ; 30 is 12 times $2\frac{1}{2}$. If, then, we take 12 ozs. of mercury and 1 oz. of turpentine at any given temperatures and mix them, the resultant temperature should be midway between the two. For example, 12 ozs. of mercury at $80^{\circ} + 1 \text{ oz.}$

of turpentine at 16° = a mixture of mercury and turpentine at 48° .

The student will have observed, that the methods used for determining the specific heats are all liable to error; part of the heat is used in heating the beaker, and part is lost by the cooling of the beaker; the metal loses heat as it is moved. In advanced books, methods are given for correcting these errors.

The high specific heat of water.—‘One pound of water in cooling through one degree will lose heat sufficient to raise the temperature of 4.2 lbs of air ($\frac{1}{237}$) one degree. But water is 770 times heavier than air. Therefore a cubic foot of water in losing one degree of temperature would raise $770 \times 4.2 = 32.34$ cubic feet of air one degree. The vast influence which the ocean must exert as a moderator of climate here suggests itself. The heat of summer is stored up in the ocean, and slowly given out during the winter. This is one cause of the absence of extremes in an island climate.’

TABLE OF SPECIFIC HEATS.

Specific heat of water = 1.

<i>Solids.</i>				<i>Liquids.</i>			
Lead	.	.	.031	Mercury	.	.	.033
Mercury	.	.	.031	Alcohol	.	.	.062
Zinc	.	.	.095	Turpentine	.	.	.426
Iron	.	.	.114	<i>Gases at Constant Pressure.</i>			
Glass	.	.	.198	Air	.	.	.237
Ice	.	.	.489	Oxygen	.	.	.217
				Water vapour	.	.	.481

EXAMPLES. VIII.

1. What is meant by the thermal unit? Write out a definition, using one gram as the unit of mass, and the Centigrade scale.

2. A mixture is made of 3 lbs. of water at 12° C. with 5 lbs. of water at 0° C. Find the temperature of the mixture.

3. A mixture is made of 4 lbs. of water at 80° C. with 10 lbs. of water at 15° C. Find the temperature of the mixture.

4. How many units of heat will be required to raise 6 lbs. of water from 0° C. to 10° C.; 10 oz. of water from 7° C. to 15° C.?

5. Explain 'specific heat' and 'capacity for heat.'

6. Why should a pound of iron heated to 100° C. sink further into ice than a pound of lead at the same temperature?

7. What is meant by the statement, that the specific heat of water is $10\frac{1}{3}$ times the specific heat of copper? If 15 lbs. of copper at 80° C. be immersed in 18 lbs. of water at 42° C., find the temperature to which the water rises.

8. What is meant by saying that the specific heat of water is 30 times as great as that of mercury? If a pound of boiling water be mixed with a pound of ice-cold mercury, what will be the temperature of the mixture?

9. What is meant by 'unit of heat'? If the specific heat of iron be $\frac{1}{9}$, and 5 lbs. of iron be cooled down from the temperature of boiling water to the temperature of melting ice, how many units of heat are evolved?

10. If a pound of boiling water be mixed with 3 lbs. of ice-cold mercury, what will be the temperature of the mixture?

11. 50 grams of copper at 80° C. are mixed with 57 grams of water at 15° . The temperature after mixing is 20° . Find the specific heat of copper. What is the capacity for heat of the fifty grams?

12. What is meant by 'specific heat'? If 8 ounces of zinc at temperature 95° C. be put into 20 ounces of water at 15° C. and the resultant temperature be 18° C., what is the specific heat of zinc?

CHAPTER IV

LATENT HEAT—FUSION—VAPORISATION

Fusion.—Heat not only changes the temperatures of bodies, but it also changes their physical state : solid ice is changed into a liquid (water), and water into a gas (steam). We have already seen that the temperature at which ice melts is constant whenever the change takes place, this temperature determines one of the fixed points of the thermometer.

Crush ice to small pieces in a mortar, and with an iron gauze spoon remove the ice to a beaker. Place the beaker in a basin containing ice and salt. Test the temperature of the clean ice with a thermometer ; in a few minutes it will be below 0° , say -8° . Remove the beaker and put it into warm water ; continue to test with the thermometer, stirring frequently ; the temperature rises, to 0° and then remains stationary. Until every particle is melted there is no further rise of temperature.

Cut up a paraffin candle, place the pieces in a beaker ; the temperature will be that of the room. Heat the beaker with a small flame, and with the thermometer stir continually the pieces of paraffin. The temperature rises gradually to about 50°C . and then the paraffin begins to melt. As soon as melting (fusion) begins, no further increase of temperature takes place until every particle of the paraffin is melted ; then the temperature of the liquid again rises.

As a result of similar experiments on solids, we obtain the LAWS OF FUSION :—

(1) Every substance begins to melt at a certain definite temperature, if the pressure remain constant.

(2) From the time fusion begins, until the time it is completed, the temperature remains constant.

The temperature at which a body melts, is called its MELTING-POINT.

To find the melting-point of wax.—Draw out a piece of glass tubing, suck a small piece of melted wax into the fine end ; when the wax sets, close the end with a small flame. Cut off about 2" of the fine tube, and fasten it by an india-rubber band to the thermometer ; place the thermometer in a flask of water (fig. 20). Apply heat to the flask, and note the temperature at which the wax melts. Remove the flame, and again note the temperature when it begins to solidify. The mean of these two temperatures is the melting-point.

Wax begins to melt at	. 49° C.
" " solidify at	. 50° C.
	2)99°
Melting-point of wax =	. 49½° C.

MELTING-POINTS.

Alcohol	. never frozen
Mercury	. - 39° C.
Ice	. 0° C.
Sulphur	. 115° C.
Tin	. 230° C.
Lead	. 334° C.
Zinc	. 425° C.
Cast iron	. 1250° C.

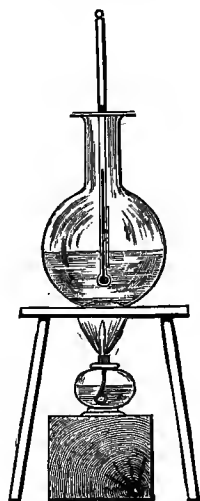


FIG. 20.

Latent Heat of Fusion.—It is evident, that a large amount of heat is necessary to melt a solid at the temperature of its melting-point, into a liquid at the same temperature ; this heat was said to be latent, and was called latent heat. The term is misleading ; the heat is no more latent than when it raises the temperature. We can imagine that the heat is engaged in tearing the solid particles asunder, in order that they may appear in the liquid form, and that until this is done the heat cannot appear as sensible heat and affect thermometers.

Arrange so that you have ½lb. of hot water in a beaker, say, at 100° C. ; weigh the beaker and water. With a gauze spoon empty into the water a number of small pieces of ice, stir until they are melted, and note the final temperature. Weigh again, the increase gives the amount of ice added. Let us suppose that 2 ozs. of ice be

used. The final temperature will be about 64° . The water cools 36° , and gives up $\frac{1}{2} \times 36$, or 18 thermal units. This amount of heat is required to melt $\frac{1}{8}$ lb. of ice at 0° to water at 0° and raise the temperature 64° ; the second part requires $\frac{1}{8} \times 64$, or 8 thermal units. Therefore to melt $\frac{1}{8}$ lb. of ice requires $18 - 8$ or 10 thermal units; and therefore to melt 1 lb. of ice at 0° to water at 0° requires 80 thermal units.

The amount of heat required to change a unit of mass (1 lb. 1 grain, &c.) of a solid into a liquid, without raising the temperature, is called the LATENT HEAT OF FUSION of that solid.

It only takes $5\frac{1}{2}$ thermal units to change 1 lb. of solid lead at its melting-point, into a liquid at the same temperature. $5\frac{1}{2}$ is the latent heat of fusion of lead; for silver it is 21, for bismuth 13, and for sulphur $9\frac{1}{2}$.

Solution. Freezing mixture.—When solids dissolve in liquids, heat is necessary to change the solid into the liquid state.

Place one tube of the differential thermometer in a basin of water. Add to the water some soluble salt such as sodium sulphate or sal ammoniac; the motion of the index shows that the temperature of the mixture is falling.

Pour strong hydrochloric acid into a beaker, add to it sodium sulphate, stir the mixture with a thin test-tube containing a little water; the temperature falls below freezing-point and freezes the water in the test-tube.

This is the principle of many ice machines. A freezing mixture—for example, ice and salt—is placed in a vessel protected on the outside by some non-conducting material such as felt. One or more of the solids passes into the liquid state, the necessary heat is taken from the mixture and the temperature falls. The substance to be frozen is placed in a thin metal vessel, which is dropped into the mixture.

Fusion of ice.—Seeing that eighty thermal units are required to melt one pound of ice, we conclude, and it can be proved by experiment, that when one pound of ice-water freezes or solidifies, eighty units of heat are given up. This is the reason why, when water is cooled down to 0° C., it does not at once freeze; every pound must lose eighty thermal units before

solidification takes place. The water is a storehouse of heat. One cubic foot of water weighs $\frac{1000}{16}$ lbs., and therefore in freezing gives up $\frac{1000}{16} \times 80 = 5,000$ thermal units, that is, sufficient heat to raise fifty pounds of water from the freezing to the boiling point. The heat acts upon the surrounding air and objects, and retards freezing. When the thaw comes it is not sufficient for the temperature to rise above the melting-point of ice; sufficient heat must be given to the ice (eighty units for every pound) to melt it; thus the thaw is gradual.

We have already seen that water, in freezing, expands and exerts great force: 11 cubic inches of water at 0° form 12 cubic inches of ice at 0° . This expansion is the cause of the bursting of water-pipes at the time of freezing; the fracture is only made evident when the thaw sets in.

Cast iron expands on freezing; thus castings made with cast iron, ice, and similar bodies are sharp, showing all the marks on the mould. Lead, gold, and paraffin contract on solidification, and are unsuitable for castings. Gold coins are stamped, not cast.

Vitreous Fusion.—Ice, paraffin, lead, and many other solids pass abruptly from the solid to the liquid state. Glass does not seem to have a definite melting-point; it first becomes pasty, and then passes gradually into a liquid state. Iron passes through a similar stage: it is in this condition that enables these substances to be welded. Pitch and india-rubber are other well-known examples.

EXAMPLES. IX.

1. Hot tea is slightly cooled by putting sugar into it. Explain this.
2. A mixture is made of 18 lbs. of water at 20° C. with 3 lbs. of ice at 0° C. Find the temperature of the mixture.
3. Sulphur melts at 115° C. At what temperature will sulphur begin to solidify?
4. On freezing water in a closed glass tube, the tube sometimes breaks. Why is this?
5. Explain why water-pipes burst during a frost.
6. The images on gold and silver coins are stamped; good castings cannot be taken. Why? Could you obtain a sharp casting of ice or of cast-iron?

7. 1 lb. of water and 1 lb. of salt, both at ordinary temperatures, are mixed. Will the temperature of the mixture change? Why?

8. What becomes of the heat that is used in melting ice? Is it lost?

9. Why does a block of ice take so long to melt, even in a warm room? Suppose heat continually poured into it, enough to raise the temperature of a quantity of water equal to the solid part of block 2°C . in a minute, how long would the block take to melt? (Latent heat of water = 80° .)

10. Suppose you have a cubic foot of ice at the melting temperature, and that you gradually apply heat to it. What changes of temperature or volume does it undergo?

11. What is meant by latent heat? Describe how to determine the latent heat of water.

12. Which will melt the more readily, a pound of lead or a pound of ice? Why?

13. 25 grams of copper at 100°C . are just sufficient to melt 2.875 grams of ice at 0° , so that water and copper are finally at 0° . Find the specific heat of copper.

Vaporisation.—When a beaker of water is heated, the following changes take place :—the temperature rises, the water expands, small bubbles of air dissolved in the water are expelled. The small pieces of floating matter show that currents are being formed, the currents rise in the centre of the beaker and flow down the sides. The water at the bottom becomes heated to boiling-point; bubbles of steam form and rise; these condense with a sharp sound before reaching the top; if these sounds be frequent, simmering ensues, if the temperature rises higher, and the bubbles escape from the surface, *ebullition* takes place. When boiling once begins, the temperature is at 100° , but it ceases to rise higher, no matter what heat is applied. The heat now supplied seems lost, and we may assume that it is engaged in tearing the particles of liquid apart so that they may exist as vapour. Other liquids behave in a similar manner when heated. If a liquid pass from the liquid to the gaseous state quietly at the surface, as, for example, when the water from lakes and rivers changes into vapour, the term *evaporation* is used. Evaporation takes place more readily when the surface is increased, when the temperature is raised, and when the atmosphere is dry.

The temperature at which a liquid boils, is called its BOILING-POINT.

The boiling-point for any particular liquid is fixed, if the pressure remain constant ; we may prove this for any liquid by the aid of the thermometer, taking the precaution to test the temperature of the vapour, seeing that impurities affect the boiling-point of a liquid. (See p. 10.)

Water vaporises slowly even when a considerable amount of heat is given to it.

The amount of heat, required to change one unit of mass of a liquid at its boiling-point, into vapour at the same temperature, is called the LATENT HEAT OF VAPORISATION. In the case of water it is frequently termed the LATENT HEAT OF STEAM.

The change of a vapour to a liquid is called *condensation*. The vapour in condensing, gives up heat, equal to the amount necessary to change the liquid to a vapour. The rapid heating of a saucer placed against steam issuing from a vessel, and the severe scalds caused by steam, illustrate the great heat given up during condensation.

To find the latent heat of steam.—We may either find the amount of heat required to change 1 lb. of water at 100° C. into steam at 100° C., or find the amount of heat given up when steam at 100° C. condenses into water at 100° C. The latter plan is the more convenient.

A is a 16-oz. flask (fig. 21) ; B, a wide tube to prevent condensed water passing into A ; C, an 8-oz. flask three parts full of water. Weigh A empty and when three parts full of water ; the difference is the weight of water. Protect A from the heat of the burner by a sheet of tin. Boil the water in C. When the steam is issuing from the end of D, note the temperature of A, and then dip D into A ; the steam condensing heats the water in A ; test with the thermometer ; in about four or five minutes remove D and note the final temperature ; weigh A and find the weight of steam condensed.

An experiment was so arranged that A contained 300 grams of water, its temperature being 13° C. At the end of the experiment the temperature was 52° C. and 20 grams of steam had condensed.

To heat 300 grams of water through 39° required 11,700 units of heat ; this heat was obtained from 20 grams of steam at 100° , condensing to water at 100° , and cooling from 100°

to 52° . In cooling it gave up $20 \times 48 = 960$ units. Therefore the difference between 11,700 and 960 units, or 10,740 units of heat was obtained from the 20 grams of steam condensing.

Therefore 1 gram condensing gives up 537 units, and we conclude it takes 537 units to change 1 gram of water at 100° into vapour at 100° . By more accurate methods the latent heat of steam is found to be 536.

The latent heat of evaporation of alcohol is 208 ; of ether 90. Practical use is made of the high latent heat of steam, in heating large masses of water : steam enters by pipes and quickly raises the temperature.

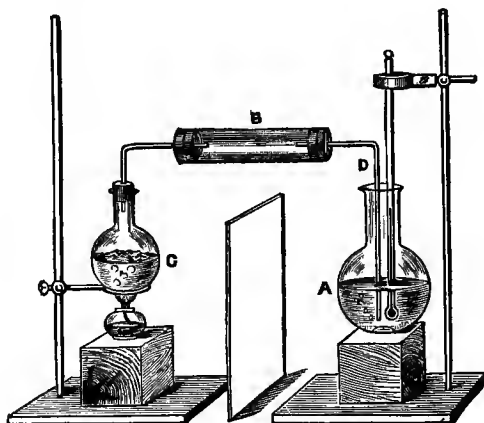


FIG. 21.

Aqueous Vapour.—Water in the gaseous state is called water vapour or aqueous vapour ; it is invisible ; the vapour as it passes along B (fig. 21) cannot be seen, nor is it visible above the boiling water in a flask. When aqueous vapour is cooled, it condenses into very small particles of liquid water, and is frequently but inaccurately called steam.

The higher the temperature of the air, the greater is the amount of water vapour it can contain ; if the temperature of the air be lowered sufficiently, part of the vapour condenses.

The temperature at which the vapour begins to condense, is called the **DEW-POINT**.

In winter the aqueous vapour in a room condenses against the cold window pane. Bring a glass of cold water into a room, the vapour in the room condenses on the outside of the glass ; if necessary, lower the temperature of the water with ice or a freezing mixture.

The air is saturated, when it can no longer take up aqueous vapour ; the air is saturated in winter sooner than in summer.

When a gas expands and overcomes a resistance, it does work, and in so doing its temperature falls. When the cork is drawn from a bottle containing any liquid under pressure, the neck is filled with finely condensed particles ; the air above the liquid before the cork is drawn is saturated ; the sudden cooling condenses part of the vapour.

Rain. Snow.—The air always contains water vapour due to evaporation. A mixture of water vapour and air is lighter than air alone ; the layer near the earth becomes heated, it expands, and becomes less dense than the layers above ; the vapour-charged air therefore rises ; the pressure upon it is reduced, further expansion ensues, and the mixture loses heat. This fall of temperature aids the condensation due to the lower temperature of the higher altitudes, and the condensed vapour forms the fine particles of water called **CLOUDS**. If further condensation takes place the minute particles increase in size and fall as **RAIN**. When the temperature falls below 0° C. the condensed aqueous vapour freezes as small crystals, the crystals unite and form **SNOW**.

Freezing by Evaporation.—The heat necessary for evaporation must come from somewhere—it may come from a flame, or it may come from neighbouring bodies, and thus lower their temperature, even to freezing-point.

Sprinkle ether on the mercury thermometer, and on the air thermometer, also on the hand. Explain why the thermometers indicate lower temperatures and the hand feels cold. Use water instead of ether.

Hammer a thin piece of copper into a shallow capsule, C (fig. 22), float it on a little water poured on a block of wood, B;

and pour carbon disulphide into the capsule ; with a bellows, N, blow across the carbon disulphide ; it evaporates, abstracts heat from the water, and the water freezes to the wood. Perform the experiment in a draught cupboard or in the open air. Ether may be substituted for carbon disulphide, but it is not so effective.

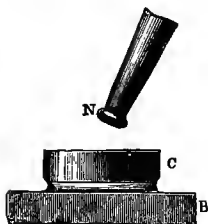


FIG. 22.

In tropical countries the water-jars are made of unglazed clay. The water oozes through the pores of the clay and evaporates on the surface, the heat necessary for evaporation is taken from the water, which is therefore kept cool. The cooling effect of a shower of rain on a hot day, is another illustration of the latent heat of evaporation.

The boiling-point depends upon the pressure.—Repeat the experiment on page 10 ; increased pressure raises the boiling-point, and we might infer that diminished pressure

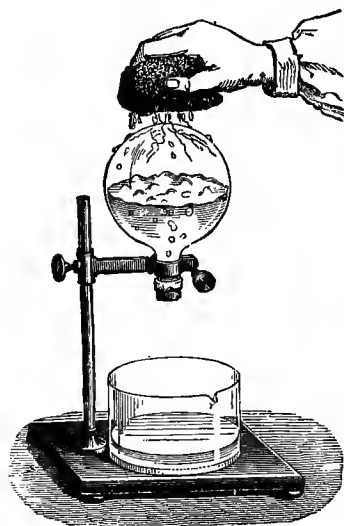


FIG. 23.

lowers the boiling - point. Under ordinary conditions, when we do not note very minute changes of temperature, the boiling-point of water is 100° C. At the hospital of St. Gothard, water boils at 91.5° C., at Potosi, in Peru, it boils at 86° C., and we infer that at both these places, the pressure of the atmosphere is less than it is in England. From other observations we know that at these and other places above the sea-level, the pressure of the atmosphere is less than at the sea-level.

Boil water briskly for five minutes in a round-bottomed flask ; while boiling insert a good india-rubber cork and at the same

moment remove the lamp ; invert the flask and let it cool. When the boiling has ceased and the temperature has fallen, pour cold water on the top. The water inside the flask again begins to boil. Pour hot water on the top ; ebullition ceases (fig. 23).

Before pouring cold water over the flask, the pressure was sufficient to prevent boiling. The cold water condensed part of the vapour, and reduced the pressure sufficiently to produce ebullition.

If a strong flask containing warm water be connected with a good air-pump and the pressure be reduced sufficiently, the water begins to boil. Interpose an intermediate empty flask between the pump and the warm water to prevent the water

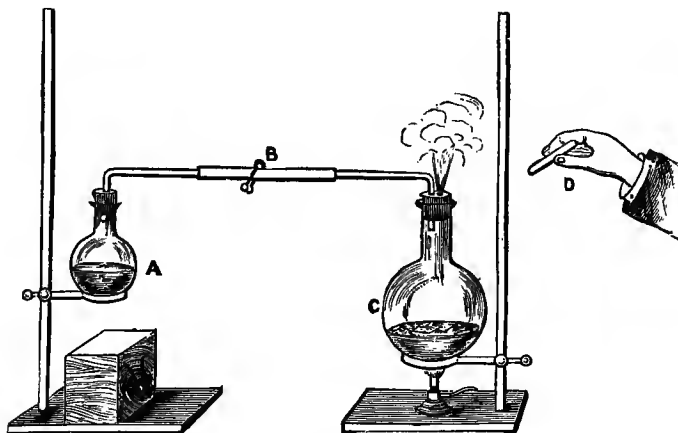


FIG. 24.

vapour from passing into the interior. We can perform the experiment by the following simple means.

Boil water in a flask, A, and let it cool down to about 60° C. Boil briskly the water in C ; close the clamp B upon thick-walled india-rubber tubing ; remove the burner, and at the same moment insert the glass stopper D. When C cools and the vapour in it condenses, connect the flask A. Open the clamp. The lowering of the pressure causes the water in A to begin to boil (fig. 24).

The boiling-point of water enables us to approximately determine heights. If water boil at 100° at the sea-level, 1,080 feet above the sea-level the boiling-point will be 99° ; thus if the boiling-point be found to be 90° , the height is approximately 1,080 feet \times 10.

Under ordinary pressure, liquid ammonia boils at 40° C., ether at 35° C., alcohol at 78° C., water at 100° C., and mercury at 380° C.

Papin's digester.—This apparatus is used for extracting gelatine from bones, or, in a modified form, for cooking on high mountains, where the heat from water boiling in an open vessel is insufficient for many cooking operations.

If the pressure be increased the boiling-point is raised.

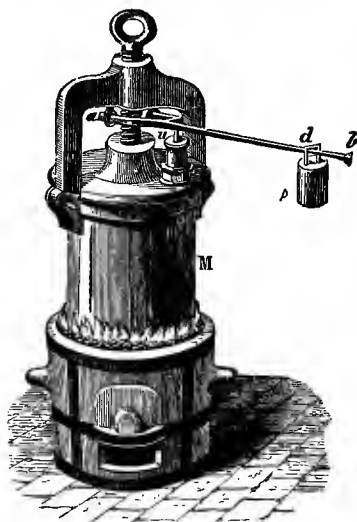


FIG. 25.

The cover of the metallic vessel M (fig. 25) is fastened down by a screw. The lever b presses upon a rod u , whose base is a valve pressing upon a hole in the cover. As the pressure increases, it raises u and the steam escapes. The pressure is regulated at five to six atmospheres by the weight p . The water can thus be heated in M to 200° C.

Distillation is a combination of vaporisation and condensation. The heated liquid passes into vapour, and the vapour, free from impurities,

is again condensed by cooling the receiver. The water obtained by distilling salt and water, for example, is free from salt. If a mixture be made of liquids having different boiling-points, the liquid with the lower boiling-point distils first. For example, the alcohol of an alcoholic liquid distils at 78° (the boiling-point of alcohol), accompanied by a small

portion of the water. A simple distillation apparatus is shown in fig. 26. A is the retort, and B the receiver.

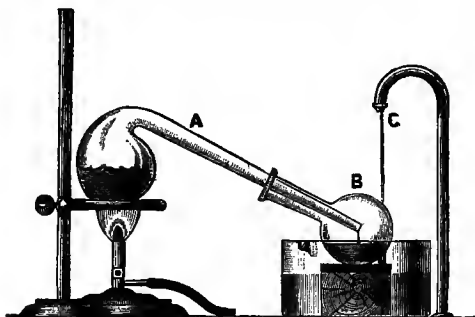


FIG. 26.

The Cryophorus.—A bent glass tube is provided with a bulb at each end (fig. 27). Water is placed in one bulb and is boiled until all air is expelled from the apparatus, the small opening that has been left is then sealed; the cryophorus therefore contains only water and water vapour.

Place the water in one bulb, A, and insert the other bulb in ice, or better in ice and salt. The water in A soon freezes.

The ice condenses the vapour in the covered bulb, the pressure is reduced and evaporation takes place from the water in A; the vapour formed is immediately condensed; heat is thus continuously taken from the water in A, its temperature falls, and it ultimately freezes.

If the outside of the bulb, A, be observed, it will be found that it is soon covered with a film of moisture, due to the aqueous vapour in the air condensing. If a thermometer were inside the bulb A, we could determine the exact temperature at which this condensation begins; and if from any cause air were reduced to this temperature, moisture would be deposited. This temperature is called the Dew-point. As

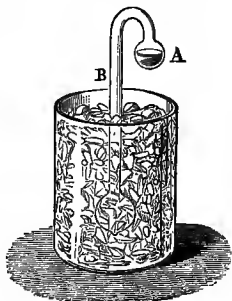


FIG. 27.

the temperature of A falls the moisture upon its surface freezes, and it becomes covered with snow.

Hygrometers.—A **HYGROMETER** is an instrument for determining the dew-point.

DANIELL'S HYGROMETER is a cryophorus containing ether and its vapour; a delicate thermometer is fixed in one bulb, A (fig. 28), the bulb B is covered with cambric upon which ether is poured, the ether evaporates and cools B, the vapour in B condenses and evaporation takes place from A; therefore the temperature of A falls. When dew appears on A the temperature, as indicated by the enclosed thermometer, is taken. On ceasing to pour ether on B the temperature of A rises again. When the film of dew disappears the thermometer is again read; the mean of the two readings is the dew-point. The thermometer on the stem gives the ordinary temperature of the air.

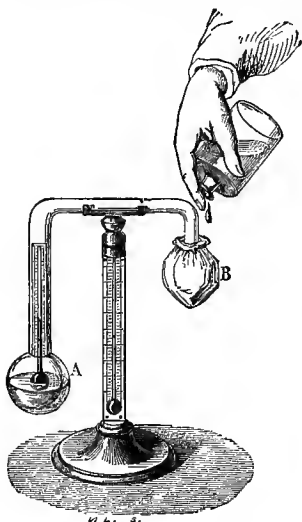


FIG. 28.

EXAMPLES. X.

1. A flask containing water is heated. When the water boils, the flask is carefully closed with a cork and removed from the flame. Explain why, when the flask is dipped into cold water, the water inside again begins to boil.
2. Explain why, in order to cook food by boiling at the top of a high mountain, you must employ a different method from that used at the sea-level.
3. What is meant by the 'boiling-point' of a liquid? How is it affected by change of pressure?
4. Explain exactly the nature of boiling. Is it possible to make lukewarm water boil without heating it, and, if so, how?
5. What is the difference between evaporation and ebullition?
6. A beaker containing water is heated by a Bunsen flame. A Centigrade thermometer, placed in the water, rises to 100° , but no higher, and the water begins to boil. What is the reason that the thermometer does not rise higher than 100° ? and what becomes of the heat which is thus apparently lost?

7. I once went into a room, the doors and windows of which had been kept shut for some time, and the temperature of which was 80° F. I took some water (also at 80°) and sprinkled it over the floor, and the temperature at once fell several degrees. How do you explain this?

8. What is meant by the 'latent heat of vaporisation'? If the latent heat of vaporisation be 966 when one degree Fahrenheit is the unit of temperature, what will it be when one degree Centigrade is the unit? Would your result be different if the unit of mass had been changed?

9. If you dip your hand into lukewarm water and then expose it to the air, the hand feels cold. If you make the same experiment with ether the hand feels much colder on exposure. Explain these facts.

10. How would you obtain pure water from sea water? What becomes of the heat in distillation that is given up during condensation?

11. Describe the changes which take place when heat is applied to one pound of ice at 0° C., until it is converted into vapour.

12. Describe 'distillation.' How could a liquid be distilled at a temperature (*a*) below its ordinary boiling-point, and (*b*) above its ordinary boiling-point?

13. A gram of steam at 100° C. is added to 100 grams of water at 0° C.; find the temperature of the mixture.

14. How much steam at 100° is required to melt 10 lbs. of ice at 0° C.?

15. What is the dew-point? How is it determined?

CHAPTER V

TRANSMISSION OF HEAT

Convection.—In ebullition, heat is carried from one part of the water to another by the heated particles of water. Transference of heat by particles is called convection.

Select a beaker as wide as possible, and pour slightly warmed water into it. Dip a test-tube containing pieces of ice into the water near the top (fig. 29).

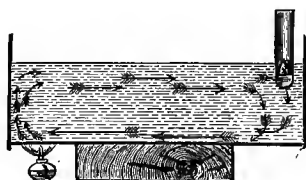


FIG. 29.

Convection currents, made visible by the impurities in the water, will be seen moving in the direction of the arrows. The water near the test-tube is cooled; it contracts and becomes denser than the water below it; it therefore sinks and other water flows to take its place.

Remove the test-tube and heat the bottom of the vessel with a small flame; again the currents circulate.

The heated water expands and becomes less dense than the water above it; it therefore rises to the top. The test-tube represents the ice of the polar sea; currents from the equator to the poles are caused by the cooled water sinking, and the surface water flowing to take its place. The direction of the ocean currents is further affected by the motion of the earth, winds, and the shape of the land.

Heating with hot water.—The apparatus in fig. 30 explains itself. A is an inverted bell-jar; B an 8-oz. flask. Fill all with cold water, and see that all bubbles of air are forced out of B. Colour

the water in A and heat the flask B. The hot water rises in the twisted tube, and cold water descends by the straight tube. B represents the boiler of a heating apparatus, A the supply cistern.

The pipe from the supply cistern always runs to the bottom of the boiler. The tube carrying the hot water should be so placed that there is a continual ascent; it must not bend downwards. The hot water in the pipes cools slowly, and, on account of its high specific heat, gives up, in cooling, its heat to buildings, and enters a comparatively cold.

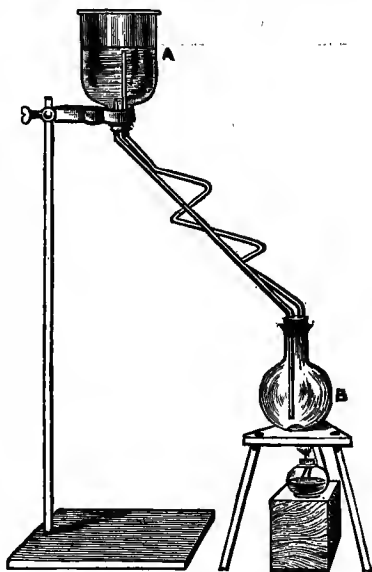


FIG. 30.

Convection in Gases.

Ventilation.—The ascent of heated air can be observed by holding smouldering

paper near a flame. The heated air expands and becomes less dense than the surrounding air; the denser cold air sinks and forces the heated air upwards. A draught is a form of convection in air, a current of cold air comes from the windows and doors, to take the place of the heated air rising in the chimney. A candle burns brighter if a tube is held over the flame; the air in the tube becomes heated, rises and a greater amount of fresh air feeds the candle; the candle represents the fire, the tube the chimney. If part of the tube be heated, the draught is improved; ventilating shafts have, therefore, frequently a gas jet burning in them. Combustion can only continue if the air be renewed, so as to supply sufficient oxygen to the flame; a lighted candle lowered into an empty bottle soon goes out.

Fasten the end of a candle to a plate, and light it. Surround the candle with water, and place a lamp-glass over the candle;

although the glass is open at the top the flame is soon extinguished. Repeat the experiment, but introduce in the middle of the glass a

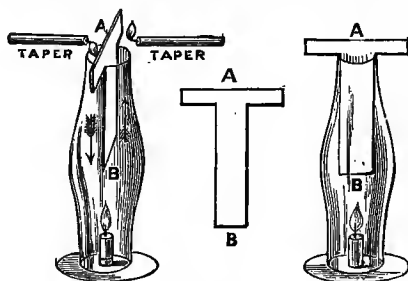


FIG. 31.

cardboard diaphragm A B; the candle continues to burn. Hold a piece of smouldering paper or a lighted taper at the sides of the diaphragm. You will discover that there is a down and an up draught, and thus the supply of fresh air is renewed to the candle (fig. 31).

Some mines are ventilated on this principle; at the bottom of one shaft c (fig. 32) a fire is kindled, this causes an up draught, and pure air rushes down the other shaft A to take its place. This is a dangerous method if the gas in the mine be explosive.

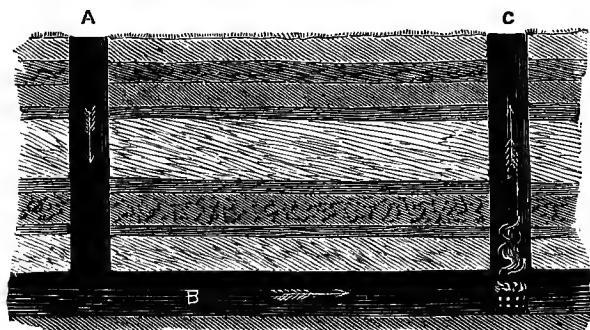


FIG. 32.

Convection of air is the cause of winds.

Conduction.—If one end of a poker be put in the fire, the other end soon becomes heated. The heat travels along the iron, from particle to particle. Transference of heat in this manner is called conduction. The end of a short poker soon becomes so hot that it cannot safely be touched, but we can touch the end of a piece of wood, of equal length, similarly

treated ; we conclude that iron is a better conductor of heat than wood.

Twist the ends of a copper and iron wire together; heat the joined ends in the flame. After some time, note the point in each farthest from the flame where an ordinary match can be ignited without friction, or find the point on each where solid wax just melts.

In an experiment, a match ignited at a distance of twelve inches on the copper wire and six inches on the iron wire ; copper is therefore a better conductor of heat than iron.

Fasten a cylinder of wood into a brass tube so that the outside diameters are equal. Wrap a piece of white paper tightly round the junction and apply a flame (fig. 33). The paper round the wood is scorched, while that round the brass is not.

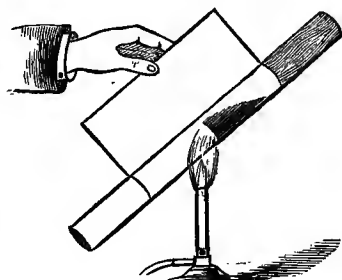


FIG. 33.

Brass is a good conductor, and conducts heat away so rapidly that it cannot burn the paper ; wood being a bad conductor does not conduct heat away so rapidly, and consequently the paper is burnt. A live coal may be dropped upon a piece of muslin spread upon a block of lead without injuring the muslin ; water may be boiled in paper, and lead melted in a pill-box ; in each case heat is conducted away so rapidly by the lead and water that the muslin, the paper, and the pill-box are uninjured.

Wrap a thick copper wire six times round a pen-holder, pass the helix over the wick of a lighted candle without touching the flame ; the candle is extinguished.

The copper conducts the heat away so rapidly that there is insufficient heat to support combustion. The experiment fails if performed with iron wire. Why?



FIG. 34.

To compare the conducting power of solids.—Clamp the air-thermometer securely, and place a cylinder of lead on the top. Heat a copper cylinder in boiling water, hold it a minute in the steam to drain, place it on the lead, and wait two minutes (fig. 34). Note the depression of the liquid in the tube. Remove the cylinder and wait until the liquid in the stem is at its original position. Perform the same experiment with similar cylinders—copper, brass, iron, tin, cork and wood—in place of the lead, always using the copper cylinder at 100° as the heater. Cylinders of cork or wood arrest nearly all the heat.

By these experiments, we can arrange the substances in the order of their conductivities. The order will be copper (best conductor), brass, tin, iron, lead, bismuth, wood, cork. In all experiments on conductivity the flow of heat must be steady. A thin layer of bismuth will conduct heat quicker than an equal layer of copper ; but after a time, when the flow of heat is steady, the flow along the copper is much greater than that along the bismuth.

The Safety Lamp.—Lower a square of iron (brass is better) gauze wire with a close mesh upon a gas flame. The flame burns below the mesh. Put out the gas, and then turn it on. Place the gauze two inches above the jet and light the gas above the gauze ; the gas burns above, but does not ignite below the gauze (fig. 35).

The gauze conducts the heat away so rapidly, that the temperature does not rise high enough to ignite the gas below. The safety-lamp used by miners is surrounded by a gauze of close mesh ; it is lighted before the mine is entered, and locked. Even if surrounded by an inflammable and explosive gas, the heat is conducted away so rapidly that the gauze is never heated sufficiently to ignite the gas on the outside. The flame goes out from lack of oxygen when the air becomes impure, and the appearance of the flame is an indication of the danger to which the miner is subjected. A strong wind, or a sound-wave caused by an exploding shot, may force the flame against the mesh, heat it or even force it through, and thus cause an explosion ; this is a source of weakness in the Davy

lamp, and endeavours are being made to render it perfectly safe.

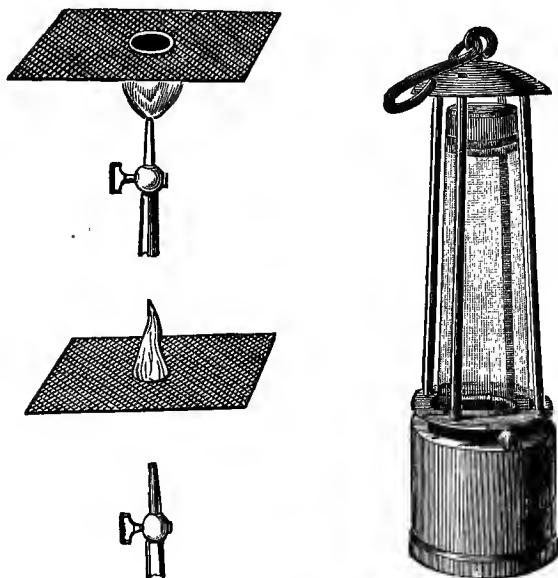


FIG. 35.

Conductivity of liquids.—Pass the air-thermometer through a bell-jar as in fig. 36. Fill the jar nearly to the top with water ; float a small dish on the top containing alcohol ; ignite the alcohol.

The index does not move, showing that water is a very bad conductor of heat.

Replace the water with mercury, and repeat the experiment ; the index moves at once.

Water and liquids generally are bad conductors of heat. Mercury is an exception, but remember mercury is a metal.

Wrap copper wire, or strips of lead, round a piece of ice ; sink it in a test-tube containing water (fig. 37). Heat the water in the upper part of the tube with a



FIG. 36.

small flame ; it can be raised to boiling-point without melting the ice, the water conducts so little of the heat. In the experiment with the air-thermometer, place ice and salt in the basin ; the index rises.

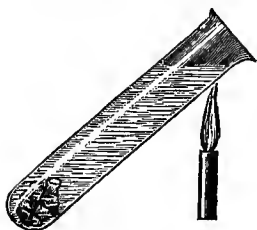


FIG. 37.

This is, however, not conduction but convection ; the water becomes denser, sinks, and then affects the thermometer.

Conductivity of gases.—The conductivity of gases is less than that of liquids ; in both, heat is, as a rule, transmitted by convection or radiation.

Cut a solid piece of lime $\frac{1}{4}$ -inch thick, place it in the hand, and touch the upper surface with the point of a hot poker. The heat soon affects the hand. Cover the hand loosely with powdered lime to the height of $\frac{1}{4}$ -inch, and put the point of the hot poker upon it. The air among the lime refuses to conduct the heat, and the hand is not burnt.

Examine the shadow of a red-hot poker ; the light passing through the heated air surrounding the poker will be refracted, and the parts near the dark shadow will be confused.

This confusion extends a very short distance below the poker, and we conclude that the air conducts heat badly ; above the poker it extends further, but this is due to the hot currents rising—that is, heat is being transmitted by convection.

Illustrations.—The feeling of warmth or coldness is due, in a great measure, to conduction. On a cold day, a piece of iron feels cold while flannel feels warm ; the metal conducts heat rapidly away from the hand ; the flannel, being a bad conductor, removes but little heat. When both are placed near a fire we can barely touch the iron, it readily gives up heat, the flannel causes little discomfort, the heat of the part we touch flows slowly to the hand, and this loss is not replaced by conduction from the other parts.

EXAMPLES. XI.

1. In the coldest or hottest weather you can handle wood without discomfort, but not metal. How is this?
2. How would you compare the conducting power of zinc and silver?
3. How would you show that (a) mercury is a good conductor and (b) water is a bad conductor? If mercury and water be both at the temperature of the room, the mercury feels colder to the touch than the water. Why?
4. Explain the construction of the safety-lamp.
5. Why are gas jets placed in ventilating shafts?
6. Why is it difficult to boil water in a 'furred' kettle?
7. When very short cylinders of lead and copper are placed with one end of each in contact with a hot body, it is found that the other end of the lead cylinder gets hot soonest, whereas with longer cylinders of the same metals the reverse appears to be the case. Explain the reason of this.
8. Explain, by the aid of a sketch, how a building is heated by hot water carried in pipes from a boiler in the basement of the building.

Radiation.¹—If the air be a bad conductor of heat, how does the heat from the fire reach us? not by convection, as the currents of air generally flow towards the fire. The heat of the sun warms the earth, and yet between our atmosphere and the sun there is no medium that conducts heat. A screen held between ourselves and a fire at once cuts off the heat; a sunshade acts similarly on a hot day. On high mountains, the heat from the sun is frequently oppressive, while a few yards away in the shade it is intensely cold. We conclude that heat passes through the air without heating it, and is only felt when stopped by our bodies or some other object. It is believed that heat is propagated by waves, and for the time being is not sensible heat; these waves strike a body and heat it. This is analogous to the propagation of light. Waves of light are not visible; we are only conscious of light when the waves strike an object and it becomes luminous. Heat transmitted in this way by wave motion is called radiant heat.

Reflection of Radiant Heat.—Radiant heat is reflected like light, the laws of reflection being the same. They can be illustrated as follows:—

¹ Radiant heat should be studied after the chapters on wave motion and light.

A divided semicircle is drawn with chalk upon a table, and two large tin tubes are placed upon it as in fig. 38. The differential thermometer is placed at T, and a red-hot ball at C; M is a reflector (a sheet of brass or bright tin). When both tubes make equal angles with the normal Mo, and only then, is the thermometer affected.

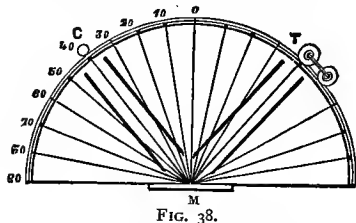


FIG. 38.

By using sheets of brass, tin, and cardboard covered with lampblack in turn, you can observe the effects produced upon the differential thermometer by a hot body c; you will find that polished brass is a good reflector, tin plate a fair reflector, lampblack a bad reflector.

By the aid of the concave mirrors, it can be shown in a striking way that radiant heat is reflected in the same manner as

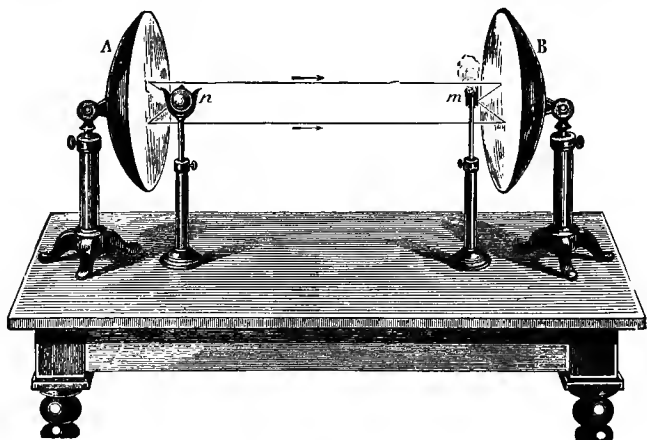


FIG. 39.

light. At one focus (fig. 39) a hot ball *n* is placed, at the other a piece of phosphorus, *m*, which is at once ignited. Point one mirror to the sun, pieces of wood and paper can be readily ignited at the focus.

As the result of experiments substances have been arranged

according to their comparative powers of reflecting radiant heat.

Polished Brass	100	Lead	60,
„ Silver	90	Glass	10
„ Tin	80	Lampblack	0
„ Steel	60		

Absorption and Radiation.—If a bright brass vessel, a bright tin vessel, a tin vessel covered with tissue-paper, and a tin vessel covered with lampblack be filled with water at 100° , and then left for ten minutes, it will be found that the water is hottest in the brass, and has lost most heat in the vessel covered with lampblack. Now fill the same vessels with cold water and put them upon a plate kept hot with a flame, or put them in front of a fire; in ten minutes test with the thermometer, and you will find that the water in the vessel covered with lampblack is the hottest, and that in the brass vessel is the coldest. That is, good reflectors such as polished brass and tin are bad absorbers and bad radiators of radiant heat; while bad reflectors such as lampblack and rough paper are good absorbers and good radiators.

The radiating power of a body is largely affected by the surface. If the surface be made smooth, its reflecting power is increased, while its radiating power is decreased.

Diathermancy.—Radiant heat is transmitted through the atmosphere and passes generally through glass. Ice transmits rays of light, but does not transmit rays of heat.

Bodies that transmit radiant heat are called diathermanous, those that do not are called athermanous. Radiant heat is either reflected, transmitted, or absorbed, thus a sheet of ice is rapidly melted by the rays of the sun, on account of the heat absorbed, while the window-pane remains cold when the sunbeams are shining upon it, showing that few rays are absorbed, most are transmitted. The amount of heat transmitted depends upon the condition of the source of heat; glass transmits fairly well the radiant heat from the sun, and the interiors of rooms are heated, but the heat rays from the furniture and walls—objects at a lower temperature—are unable to pass through the glass. Heat, therefore, accumulates in the room.

Aqueous vapour transmits freely the heat from the sun (body at a high temperature) during the day, but it serves as a screen to prevent radiation at night, being athermanous to heat from sources at a low temperature.

‘Remove for a single summer night the aqueous vapour from the air that overspreads this country, and you will assuredly destroy every plant capable of being destroyed by a freezing temperature. The warmth of our fields and gardens would pour itself unrequited into space, and the sun would rise on an island held fast in the iron grip of frost. The aqueous vapour constitutes a local dam by which the temperature of the earth is deepened ; the dam, however, finally overflows, and we give to space all that we receive from the sun.’¹

Winds.—The earth is heated at its surface by the rays of the sun, land and water receiving the same amount of heat for equal areas ; this heating is greatest at the tropics. The heated earth heats the layer of air near it, this layer expands and becomes less dense than the air from the temperate and polar regions that rushes in to take its place, the motion of the wind being modified by the revolution and shape of the earth.

Land and sea breezes.—During the day the land absorbs the heat of the sun ; its specific heat being low it is soon heated and its temperature rises. The water reflects most of the sun’s heat ; this, combined with its high specific heat and its motion, prevents any marked change in its temperature. The air above the land is thus heated more than that above the water, it ascends and a breeze sets in from sea to land. At night the earth radiates its heat rapidly and the sea slowly ; soon the temperature of the land falls below that of the sea, and a land breeze ensues.

Mechanical equivalent of Heat.—In the first section of the work it is seen that when work is done by friction, hammering, etc., heat is produced. Dr. Joule made a falling weight turn a paddle in a vessel of water, the weight being attached to a cord that passed round the axle of a wheel connected with the paddle ; he knew the work done by the falling weight and observed the rise of temperature in the water. From an enor-

¹ Tyndall, *Heat a Mode of Motion*.

mous number of experiments he deduced that 1 lb. falling 772 ft., or 772 lbs. falling 1 foot, is capable of raising the temperature of 1 lb. of water 1° Fahrenheit. 772 ft.-lbs. of work is the mechanical equivalent of heat on the Fahrenheit scale. 1390 ft.-lbs. of work ($772 \times \frac{9}{5}$) will raise the temperature of 1 lb. of water 1° Centigrade. These are important numbers in physical science. Suppose we find that an electric current is capable of heating 2 lbs. of water through 3° Centigrade in one minute, we deduce that the mechanical equivalent of the current is 6×1390 ft.-lbs. of work per minute.

In a steam-engine the heat from the combustion of coal, heats the water and changes it into steam, the pressure of the steam moves the piston and the engine does work; let us suppose that it raises a weight. The energy of the coal is transformed into the energy of the steam, this in its turn is changed into the energy possessed by the weight by virtue of its position. Theoretically, in a perfect engine the energy of the coal would exactly equal the energy of the weight, were it not that part is transferred by friction of the parts of the machine into heat, which heats the machine but does no useful work.

It will form a useful exercise to calculate the amount of heat required to change 1 lb. of ice at 0° F. into steam at 212° F.

The specific heat of ice is $\cdot 5$, the latent heat of ice is 144 (on the Fahrenheit scale); the specific heat of water we may take uniformly as 1; the latent heat of steam is 965 (Fahrenheit scale).

	Thermal units.
1. To raise 1 lb. of ice from 0° F. to 32° F. (melting-point) requires $\cdot 5 \times 32$	= 16
2. To melt 1 lb. of ice at 32° F. into water at 32° F.	= 144
3. To raise 1 lb. of water from 32° F. to 212° F. (boiling-point)	= 180
4. To change 1 lb. of water at 212° into steam 212° F.	= 965
Total	1305

The mechanical equivalent of the thermal unit on the Fahrenheit scale is 772 ft. lbs., therefore to effect the above change would require 772×1305 , or 1,007,460 ft.-lbs. of work.

An engine of one horse-power does 33,000 ft.-lbs. of work per minute. It would take such an engine more than half an hour to effect the changes.

EXAMPLES. XII.

1. Why is glass used in a greenhouse?
2. Explain Franklin's experiment : he placed several pieces of coloured cloth upon snow when the sun was shining ; he found that the darker pieces sank farther than the lighter ones.
3. Polished fire-irons in front of a big fire are cooler than rusted fire-irons. Give the reasons.
4. Is brick or polished steel the best substance for the back of a fire-place?
5. Neglecting the weight, will a helmet of polished brass or one of white cloth be the cooler in the sun's rays ? Why?
6. Explain how to determine the emissive powers and the absorbing powers of substances for radiant heat, and state the relations which exist between them.
7. How are the radiation, reflection, and absorption of heat related to one another?
8. Will water boil as quickly in a bright metal kettle as in a kettle that is blackened with use ? Which will retain the heat the longer after they are removed from the fire ?
9. Should a kettle intended to be heated by standing in front of a fire be bright or black ? State fully the reasons for your answer.

SOUND

CHAPTER I

PRODUCTION AND SPEED OF SOUND

Vibration.—The pendulum of a clock swings from side to side, and as long as the length remains constant, it makes a fixed number of swings every minute. The motion from one side to the other is called an *oscillation*; a motion from one side to the other and back again is called a *vibration*.

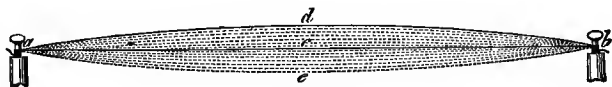


FIG. 40.

The cause of sound.—The vibrations (from *e* to *d* and back to *e*) caused by plucking a tightly stretched cord are so rapid that we are unable to count them (fig. 40). A sound due to the vibrating string is heard. That a wine-glass vibrates, when it rings, is easily shown (in fig. 41 a bell-jar is used); a small bead is placed inside the glass; on striking the jar with a piece of wood, it rings, and the bead is forced from place to place by the vibrations.

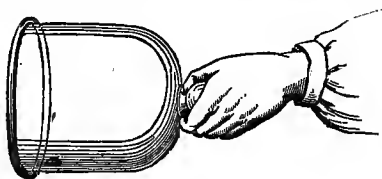


FIG. 41.

The vibrations of plane glass or metal plate can be beautifully demonstrated, by a method due to Chladni.

Grind the edges of a glass plate, 9" square, smooth, on a grind-stone ; place the glass on an ordinary reel. Sprinkle fine sand upon its surface and press the centre firmly with the thumb. Let an assistant touch it at one part, while a violin bow is drawn over another part. In fig. 42 the plate is attached to a stand. The simpler method given above is sufficient.

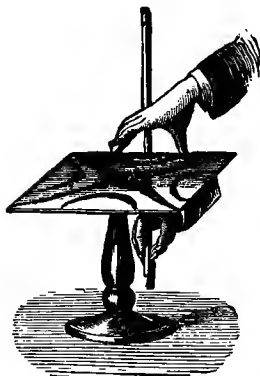


FIG. 42.

When a sound is produced, the particles of sand are thrown into movement. They move from the parts of the plate that vibrate, and collect along lines where there is no motion.

The vibrations of a tuning-fork are sufficiently marked to force away a suspended bead.

A body that emits a sound is called a *sonorous body*. *All sonorous bodies are in a state of vibration*. Sounds are caused by rapid vibrations.

Sound is not produced in a vacuum.—Each vibration of a sonorous body gives a push to the air, and the air transmits the pushes to the ear ; the air, or some other medium, is essential. When an alarum is rung under the receiver of an air-pump, the air being exhausted, scarcely any sound can be heard. If the air could be completely exhausted, and the alarum suspended, so that the vibrations were not transmitted by the solid parts of the air-pump, no sound would be heard (fig. 43). This can be illustrated by a simple piece of apparatus.

A strong flask is provided with a good india-rubber cork having two holes (fig. 44). A piece of glass rod passes through one hole, and is connected with a toy bell by india-rubber tubing. The cork is inserted, the bell rung by shaking the flask, and the sound produced noted. The bottom of the flask is then covered with water, and the whole warmed ; it is then held over the naked flame, and while the water briskly boils, the flask is removed from the flame, and at the same instant a glass stopper is inserted in the other hole.

As the flask cools the water condenses, and leaves a good vacuum, that fails to conduct sound. On shaking the flask, the sound produced is feeble compared with the sound heard when the flask contained air.

Having removed the stopper (first warm the apparatus), empty and dry the flask and hold it over a gas jet ; when full of gas replace the cork and ring the bell.

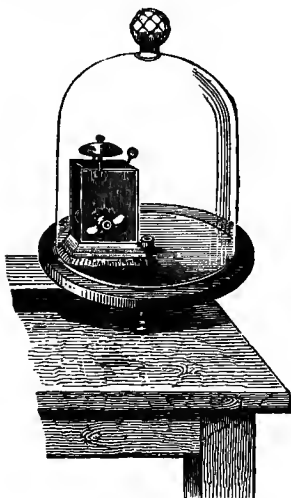


FIG. 43.

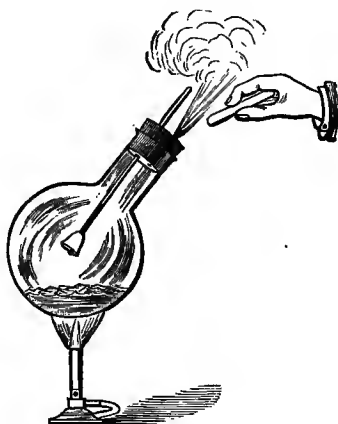


FIG. 44.

The sound is louder than that produced in the vacuum, but feebler than when the flask was full of air. If filled with hydrogen, the sound is feebler than with coal gas ; on the contrary if filled with carbonic acid gas the sound is louder. Coal gas and hydrogen are lighter than air, while carbonic acid gas is heavier than air.

The loudness depends upon the density of the gas, in which the sound originates, and not upon the gas (air) surrounding the person who hears the sound.

The air becomes rarer as we ascend ; on very high mountains the report of a pistol shot is not louder than that of a good pop-gun. If, however, a cannon be fired in the valley the sound

heard half a mile away, on a mountain-top, is as loud as that heard by a person in the valley an equal distance away.

The speed of sound in air.—The flash of lightning is seen before the sound of the thunder is heard. We may observe a workman at a distance deliver a blow before we can hear the sound produced by the blow. If a sea-target, a cannon, and a spectator be placed at the corners of an equilateral triangle, the spectator sees first the flash, then the column of water caused by the shot striking the sea, and last of all hears the report. The speed of sound in air is therefore less than that of light, and less than the speed of a cannon ball. A bird within range has no intimation of danger by the report preceding the shot.

In order to determine the speed of sound in air, the distance between two places is exactly measured. A cannon is fired at station A, and an observer at station B notes how long the report is after the flash is seen; a cannon is then fired at B, and an observer notes the time at A, and the average result is taken. For example if two stations were 60,000 ft. apart, and the report was heard fifty-five seconds after the flash was seen, the speed of sound would be $\frac{60,000}{55}$ feet per second—that is, nearly 1,100 feet per second. Experiments have shown that the speed is greater on hot than on cold days. At 0° C. the speed is 1,090 feet per second. To find the speed at any other temperature add 2 feet for every degree above 0° C.; thus the speed when the air is at 15° C. is (1090 + 30) feet per second.¹ Sound travels quicker with the wind than against it.

All sounds, whether high or low, travel at the same speed, otherwise it would be impossible to distinguish a tune played by a band at a distance; the sounds would intermingle.

The speed of sound in water.—Liquids transmit sounds.

Close a glass tube 18" long, $\frac{1}{2}$ " wide, at one end, fasten it perpendicularly by wax to a thin deal board, about 2 feet square, and fill it with water. Rest the board upon three corks. Arm the stem of the tuning-fork with a cork cone. Strike the tuning-fork and observe the loudness of the sound when the fork is held in the

¹ Light travels so rapidly (186,000 miles per second) that the time it takes to travel any ordinary distance may be neglected.

hand; strike it and rest it on the board, the sound is reinforced. Again strike it, and plunge the cone into the water in the tube. The sound is transmitted by the water to the sounding-board, and the increase in intensity is evident.

By experiments similar to those for determining the speed of sound in air it has been found that the speed of sound in water is 4,700 feet per second—that is, about four times the speed of sound in air.

The speed of sound in solids.—It is a common experiment for one person to place his ear against a telegraph post, while another strikes the next post. Two sounds are heard: the first, the more distinct, is transmitted by the wire, the second by the air. Sounds travel quicker in solids than in air, and are conveyed with greater intensity.

Strike a tuning-fork and rest its root on one end of a deal rod; place a thin square board on and off the other end. The sound travels along the rod, is communicated to the board, and the intensity increases.

The speed of sounds in solids is so great that methods similar to those for determining the speed in air and water cannot be used with accuracy. The speed of sound in iron is about 17,000 feet per second, and in copper 11,000 feet per second.

EXAMPLES. I.

1. How would you show that sound is not transmitted by a vacuum?
2. Give some familiar evidence that sounds of all kinds travel nearly at the same rate.
3. Describe any experiment which occurs to you for showing that sound is capable of being transmitted through liquids.
4. Explain in what way the velocity of sound in water has been experimentally determined.
5. You see a flash of lightning and you hear the thunder which follows. Supposing the velocity with which the sound of thunder travels through the air to be known, how would you determine the distance of the lightning flash?
6. The temperature on a certain day is 15° ; the report of a gun is heard 6 secs. after the flash is seen. How far is the spectator from the gun?
7. Standing some distance from a quarry, I hear two sounds following the blow the workman gives to the rock. Explain this.

CHAPTER II

TRANSMISSION OF SOUND—WAVE MOTION

Water-waves—vertical waves.—When a stone is thrown into a pond, waves proceed from the point where the stone strikes the water to the margin of the pond ; pieces of wood or leaves that may be floating in the water are not washed to the bank, they simply move in a path that is more or less circular and return to their original positions, their average positions remain fixed. If a patch of water be blackened with ink, the wave in moving over the patch does not force it onward. The form of the wave moves forward ; the particles of water that form the wave merely move up and down.

Waves cross a field of long grass under the influence of the wind ; the form of the wave alone moves forward, the tips of the grass do not move onward. A bargeman, when he wishes his rope to clear an obstacle, sends a wave along it ; the rope itself does not move forward.

Fasten a leaden bullet to a fine piece of cord suspended from a hook, so that the distance from the point of suspension to the centre of the bullet is thirty-nine inches. Set it swinging, and note the time it takes to move sixty times from side to side ; it will be about one minute.

This pendulum *vibrates* once every two seconds, and *oscillates* once per second. Give the bullet the necessary impetus, set it swinging in a horizontal circle, and count how many circles it completes in 20 seconds ; the number will be about 10. It completes 1 revolution in the time it took to make a vibration. Place the eye so that the path appears as an ellipse, and then as a straight line (fig. 45). The bullet increases its speed from each end until it reaches the middle of the line ;

then it slackens until it reaches the far end of the line, when it momentarily stands still, then returns again, quickening up to the middle. Seeing that it moves uniformly in the circle, it appears to the eye to pass over the distances AL, LK, KJ . . . in equal times. When a body vibrates along a line, as the bullet appears to vibrate along AG, the motion is called harmonic motion. If we place the eye beneath an ordinary pendulum, so that its path appears a straight line, the motion is harmonic.

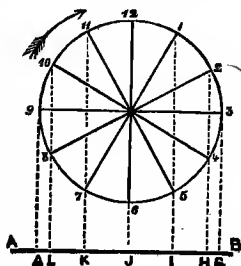


FIG. 45.

The distance AG (the diameter of the circle) is called the **AMPLITUDE OF THE VIBRATION**. The time of moving from A to G and back again to A—that is, the time of a complete revolution of the circle—is called the **PERIOD OF THE VIBRATION**.

Suppose a number of particles move in parallel straight lines ABCD . . . with harmonic motion, so that each succeeding particle is $\frac{1}{12}$ of a revolution behind the other; and suppose the time of a revolution (the period) be 1 second. The position of the particles at any time can be determined from the generating circle (fig. 46).

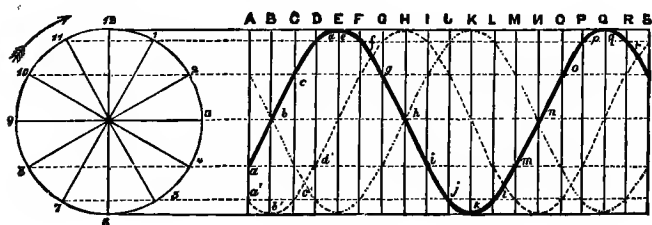


FIG. 46.

If the particle *a* in line A, be represented at 4 in its circle, then the particle in B being $\frac{1}{12}$ of a second behind will be at 3 in its circle—that is, it appears on the line B at *b*, and so on for *c*, *d*, *e*, *f*, *g* . . . Join these particles, and the thick sinuous curve is formed; call this the first position of the wave.

$\frac{3}{4}$ of a second later a will have moved from 4 to 7, that is to the end of the line A and back to a' . The other particles will be at $b' c' d'$, and the dotted curve $a' b' c' d' \dots$ is formed; this is the position of the wave after $\frac{3}{4}$ of a period; the wave is moving from A towards S. $\frac{6}{4}$ of a second from starting the wave is in the position ----- In $\frac{3}{2}$ of a second the particles will be in their original position, but the wave will have moved from E to Q or from A to M.

The top of a wave is called a crest, the hollow the trough. The distance from crest to crest, or from hollow to hollow, is called a wave-length. In $\frac{1}{4}$ period from starting the crest is at

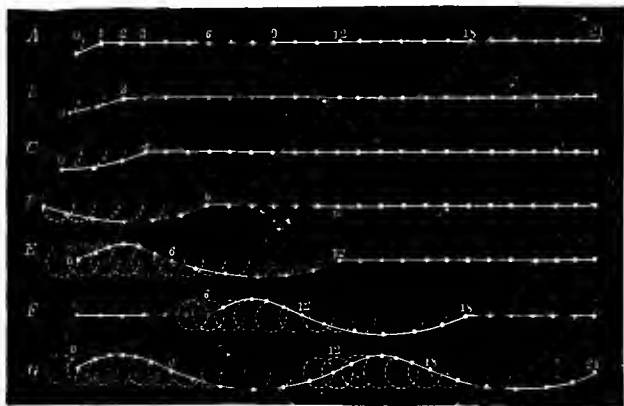


FIG. 47.

H, in $\frac{6}{4}$ period at K, in a complete period at Q. *The distance the wave travels in one period is ONE WAVE-LENGTH.*

For simplicity we have supposed that the particles in fig. 46 move in straight lines; they may move with harmonic motion in ellipses or circles. Suppose 0, 1, 2, 3, . . . a number of particles at rest (fig. 47), and that 0 begins to move in a circle, the period being one second, and that each particle follows $\frac{1}{4}$ second later than its predecessor. A B C D E represent the positions at the end of $\frac{1}{4}$, $\frac{2}{4}$, $\frac{3}{4}$, $\frac{6}{4}$, and $\frac{5}{4}$ period. From 0 to 12 (E) is one wave-length; 0 is in its original position. If after one revolution the particles rest, one wave moves along,

and in $1\frac{6}{12}$ period the position is F. The wave has advanced half a wave-length from the position in E. If the particles keep moving the waves are repeated as in G.

In all these illustrations the particles do not change from their average position; the form of the wave alone moves forward.

Longitudinal waves.—The preceding explains water-waves, the waves that pass along ropes, and, as we shall see later, the waves of light and radiant heat. There is, however, another method by which waves can be transmitted.

Fill a piece of india-rubber tubing 12 feet long and $\frac{1}{4}$ diameter with sand, and hang it from the ceiling; near the top make a distinct chalk mark, hold the end in one hand, so as to slightly stretch the tube; with the fingers of the one hand rub it along its length.

A wave passes along the tube, as is shown by the movement of the mark; it is reflected at the top and moves back.

Wrap a long steel wire round a cylinder of wood 2" diameter, so that the coils are $\frac{1}{2}$ " apart. On removing the cylinder a spiral is formed. Suspend the coil horizontally, this is done by attaching two threads to every tenth coil and fastening these threads to the parallel horizontal laths. Gather a few coils at one end into the hand; on releasing them observe the compression travel to the other end of the wire.

In the last two experiments a wave passes along the tube and helix; the particles move backwards and forwards in the line of direction, but do not change their average positions.

Cut a narrow slit *ss* in black paper B (fig. 48). Place it along the dotted line of A. Draw A beneath the slit in the direction of the arrow; the dot that is seen, vibrates backwards and forwards; its motion is harmonic, as we see from the form of the sinuous curve.

A number of particles moving backwards and forwards, one moving a little after the other; will produce a wave; there will be a compression (the particles come together) succeeded by a rarefaction (when the particles move apart, relative to each other) like the compression and rarefaction that travelled along the coil.

Place the slit along the dotted line *c*, fig. 48; draw the book in the direction of the arrow.



Each curve in *c* is similar to *A*. They are arranged so that each dot produced with the slit moves a little later in its path than the preceding dot. The wave of compression and rarefaction will be seen travelling across the slit. Compare the parts of greatest compression with crests of waves, the parts of rarefaction with troughs of waves (fig. 49). The wave-length is the distance from one compression to the next (from *c* to *c* (1)), or from one rarefaction to the next (from *r* to *r* (1)), or from one particle to the next particle in a similar position, and moving in the same direction; and as in the case of vertical waves, the wave will move one wave-

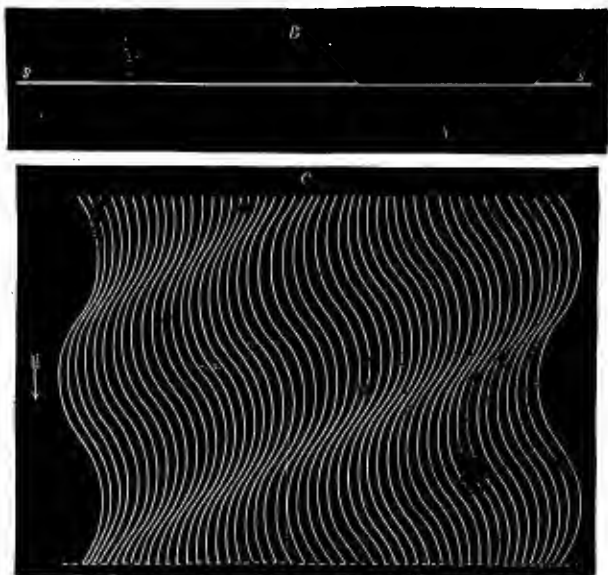


FIG. 48.

length in the time it takes a particle to make a complete vibration.

Sound-waves.—Sound-waves are transmitted by the air-particles vibrating in the line of direction. When a body vibrates with sufficient rapidity, the particles of air surrounding it are set in motion and sound-waves are formed.

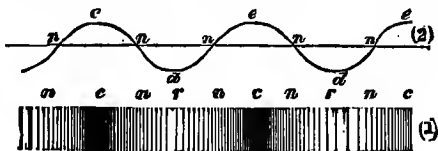


FIG. 49.

The motion is communicated by each particle to the next, the motion of the particles near the ear affect that organ, that is, energy is transmitted by the sound-waves to the ear and a sound is heard. When a gun is fired the sound-waves travel ; there is, however, no tendency

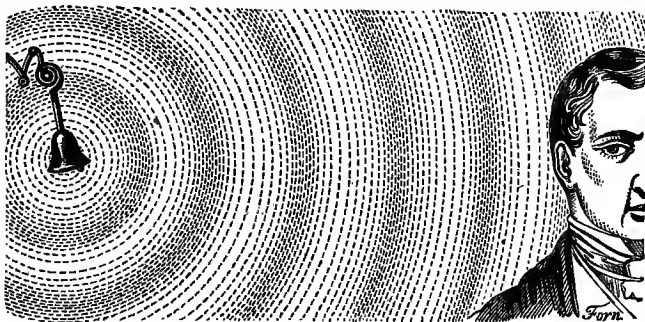


FIG. 50.

for the smoke to move in straight lines in all directions as the sound-waves do. The propagation of sound-waves is not the propagation of air-particles.

Insert a funnel in one end of a long wide india-rubber tube, direct the other end towards a lighted candle, and blow a little smoke into this end. Beat two pieces of wood together near the mouth of the funnel ; the candle is extinguished by the sound-wave, but the smoke is not forced through the tube.

Such sound-waves from firing shots in mines (it has been

suggested) cause explosions, by forcing impure gas through the meshes of the Davy lamp (see p. 47). Sound travels in all directions. A skylark singing is the centre of a sphere of sound-waves, and every particle in the sphere is vibrating.

Fig. 50 gives a rough idea of the sound-waves caused by a bell. At equal distances from the point of disturbance all the particles will be in similar positions, and will form the surface of a sphere; such a surface forms the **FRONT OF THE WAVE**. If we consider a *very small portion* of the surface of a sphere, it will practically be a plane surface; so that the wave-front is a plane surface, and the direction of the wave is at right angles to this surface.

Elasticity.—Set a dozen solitaire balls in a groove; move one and roll it against the eleven; the end one starts off the row, while the intermediate balls are apparently motionless.

In the water-waves, the particles moved upwards on account of the impulse given to the wave (the stone falling in the pond, &c.), and downwards on account of the action of gravity. How can we explain that when a particle moves forward, it returns on its path and moves backwards? Why do the solitaire balls transmit motion?

Definition.—When a body, after being compressed by a force, recovers its original shape when the force is removed, the body is said to be elastic.

It requires a certain force to compress a piece of putty, but on removing the pressure the original shape is not regained; putty is therefore inelastic.

Cover a flat stone with red powder, touch it with a solitaire ball, and notice the dot made. Allow the ball to fall from a height of three or four feet upon the stone and examine the dot made; it is larger than before, the ball has been flattened, but when the pressure was removed it regained its original shape. The glass ball is elastic. Allow a leaden ball to fall, the flattening remains.

Glass is elastic; lead is inelastic.

Each time one prong of a vibrating tuning-fork advances, it gives a push to the air; the particles are compressed, and by their elasticity resist compression; they expand, compressing the

next set of particles ; these, in their turn compress the next set, so that the compression is propagated. When the prong moves back it causes a rarefaction ; this rarefaction is transmitted in the same way as the compression. The tuning-fork makes a series of backward and forward movements, and thus a series of condensations and rarefactions are produced, which constitute sound-waves. The particles recover themselves on account of their elasticity, and transmit the wave just as the solitaire balls did ; each ball, representing a particle of air, was compressed for a short time, it then expanded on account of its elasticity and communicated the compression to the next ball.

EXAMPLES. II.

1. Give an example of harmonic motion.
2. Define the terms oscillation, vibration, amplitude, period.
3. Give examples of wave-motion. Explain crest and hollow.
4. Define wave-length.
5. In what direction do the particles in a water-wave move ?
6. There are five crests between a boat and the shore, a distance of 100 feet. Calculate the average wave-length.
7. What is meant by a *wave of sound* and by the *length of a wave* ? Explain how sound is transmitted through air.
8. Compare the direction of the motion of the particles in a water-wave, and the wave in a wire spiral.
9. Define wave-length. Suppose the amplitude of vibration of the particles be doubled, how will this affect the wave-length ?
10. Explain condensation, and rarefaction.
11. Give illustrations and experiments to show that when a sound-wave is transmitted, the air-particles do not leave their average position.
12. Explain elasticity ; give examples of elastic and inelastic substances.
13. Explain how the condensation and rarefaction constituting a wave of sound are produced. How is a sound-wave propagated through air ?
14. Take the speed of sound as 1,120 feet per second. Find the wave length (*a*) if there be 280 vibrations per second, (*b*) if the period of the particles be $\frac{1}{440}$ second.
15. Sound-waves are 1·2 foot long ; the air-particles make 1,000 vibrations in a second. Find the speed of sound.
16. Explain the action of the toy telephone made of two cardboard boxes connected with string.

CHAPTER III

THE INTENSITY AND REFLECTION OF SOUND

Intensity.—The further the ear is from a sonorous body, the feebler is the effect as regards sound upon the ear. As in all cases of straight line motion, *the intensity varies inversely as the square of the distance*; that is, the intensity of sound at a distance of 200 yards is one-fourth the intensity at 100 yards.

The intensity depends upon the density of the medium in which the sound originates (p. 57).

Make the tuning-fork sound, then place the end upon the table, or, better still, on a thin board suspended by threads; observe how the sound is increased. Sprinkle fine sand upon the thin board; the sand moves, proving that the board is vibrating. A string stretched tightly over two nails in the wall produces scarcely any sound when it vibrates; stretch the same string on supports inserted in a box with a thin cover: the sound is increased.

The area of a vibrating body may be so small, that the number of air-particles set in motion are unable to affect the ear, or affect it slightly; when the vibrations are transmitted to a larger area, a larger number of particles are set in vibration and these cause a distinct increase in the intensity. The wall in the experiment is so thick and so firmly fixed that it is unable to vibrate; the thin wood readily vibrates and increases the intensity. For this reason musical instruments are provided with sounding-boards; in the violin the thin wood forming the belly vibrates when the string is bowed; the post communicates the vibration to the back, which also vibrates. A tuning-fork held in the hand sounds *longer* than when its root rests upon a sounding-board; the energy is communicated to a larger surface

and is the sooner used up. We gain in the intensity of the sound, but lose in the time the sound lasts.

The intensity depends upon the area of the sonorous body.

If in fig. 46 we double the diameter of the circle, that is, double the amplitude of vibration, while the period remains as before; each particle in A B C . . . must move with twice its former speed. The waves will be higher and will have a greater effect upon any obstacle, their capacity for doing work will be four times their former capacity. In a similar way if the amplitude of the particles in sound-waves be doubled or trebled, the capacity of the waves for doing work will be four times or nine times their former capacity, and will have four times or nine times their former effect upon the ear. The amplitude of the vibrations of the air-particles, will be the amplitude of vibration of the sonorous body.

The intensity depends upon the amplitude of the vibration of the particles; if the amplitude be doubled the intensity is quadrupled; *the intensity varies as the square of the amplitude of the vibrations of the sonorous body.*

A sensitive flame.—Bend a piece of glass tubing at right angles. Draw out one end; cut off so as to leave a very small orifice. Connect the other end with the gas supply (fig. 51); 2" above the orifice place a square piece of brass gauze 6" side; turn on the gas, ignite it above the gauze, and surround the flame with a wide piece of glass-tubing about 6" long. Turn the gas-tap until the flame just does not flare.

The vibration of the air-particles of sound-waves affect the gas below the gauze, and the flame flickers. Rattle keys, tap on the table, hiss, or whistle, the flame is in every case affected.

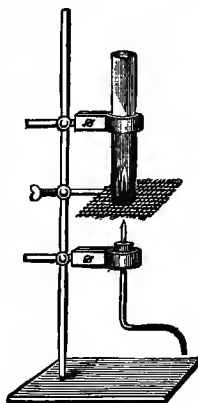


FIG. 51.

Reflection of sound.—Draw a semicircle on the table with chalk, graduate it as in fig. 52, and arrange the tin tubes along radii each making 45° with the normal. Place the sensitive flame at the end of one, A, and several

damp towels, B, between A and the end of the other tube. Tap two pieces of metal together inside the second tube, adjust the flame, and use more damp towels if necessary until the flame does not respond to the taps. Place a reflecting surface, a plane mirror, a sheet of paper, or the hand, at C.

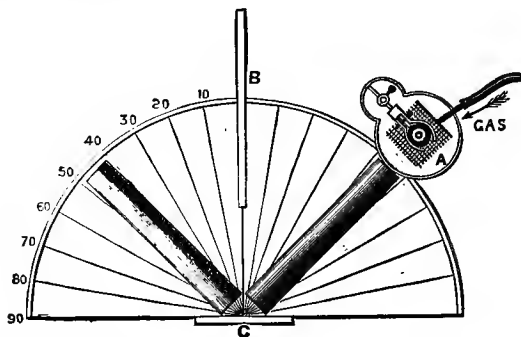


FIG. 52.

The flame is at once affected by the taps. Remove the reflector, the flame steadies. If A be placed making an angle of 40° with

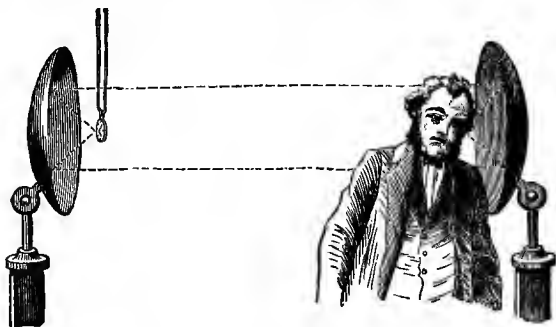


FIG. 53.

the normal, then the other tube must make the same angle. The sound-wave which travels down one tube is reflected at C. A watch may be substituted for the taps and the ear for the sensitive flame.

Sound is reflected similarly to light (p. 94). The angle of incidence is equal to the angle of reflection.

Dry towels, sheets of paper, do not serve as effective screens,

and we conclude that they are poor absorbers of sound-waves, while damp towels are good absorbers of sound-waves.

By using two large concave reflectors, we can further illustrate the reflection of sound (fig. 53). When a watch is placed at the focus of one mirror, a person can hear the ticks by placing his ear at the focus of the other mirror, although the distance may be such, that when the second mirror is removed, he is unable to hear the ticks. The sound-waves from the watch strike the near mirror, are reflected parallel to the principal axis, and after meeting the second mirror, are again reflected to its focus. This is better demonstrated by substituting the taps for the ticks of the watch, and the sensitive flame for the ear.

Whispering-galleries.—We can easily understand that if a gallery be of a certain shape, the whisper of a person in one part may be quite audible to another person beyond ordinary range of sound. Regard the two mirrors in fig. 53 as the opposite side of a semicircular gallery.

Speaking-tubes.—The use of the tubes in the experiments



FIG. 54.

is, that the waves of sound reflected are from the interior and are thus prevented from spreading. Instead of the intensity

being inversely as the square of the distance, there is but a slight diminution of sound.

Reduce the sensitive flame until it is not affected by the taps produced from two pieces of metal, at a distance of 15 or 20 feet. Fit the large tin tubes end to end, and place them between the flame and the source of sound so that the taps are made close to one end. The flame at once responds.

If we use a long india-rubber tube, half-inch wide, and place one end to the ear, the slightest sound made at the other is distinctly heard. Bending the tube, provided it be not closed, does not affect the experiment. The speaking-tubes used in offices are made of strong caoutchouc, provided at each end with an ivory or bone mouthpiece (fig. 54).

Echoes.—Reflection of sound is the cause of echoes. The sound-wave travels to a reflecting surface—such as the walls of a building, the sides of a mountain, or the trees at the edge of a forest—is reflected, and travels back to the ear ; the sound now heard is called an echo. It is difficult to distinguish words that strike the ear at less intervals than one-tenth of a second—that is, the wave must travel $\frac{1100}{10}$ feet, or 110 feet, therefore the surface must not be less than 55 feet distant. Standing between two reflecting surfaces, the sound-wave, reflected from each, proceeds to the opposite surface, and is again and again reflected, each echo being fainter than the preceding one. Two or more echoes may also be caused by two or more parts of a reflecting surface at different distances from the observer, as, for example, from the parts of the edge of a wood at varying distances.

EXAMPLES. III.

1. Explain the meaning of intensity of sound ; how does the intensity vary with the distance from the sonorous body ? If the intensity at a distance of 100 feet be 90, what will it be at a distance of 150 feet ?
2. State the conditions that affect the intensity of sound. What is a sounding-board ? Why is it used ?
3. How could you illustrate the reflection of sound ? Describe a speaking-trumpet. Explain the principle of a speaking-tube.
4. What is an echo ? An echo from a building is heard 30 seconds later than the sound ; how far is the building distant ?

5. A person is walking between two parallel walls which are near together, and hears a prolonged echo of each footstep; explain how the echo is produced.

6. Compare the intensities of sound at two places, one 1,100 feet, the other 1,800 from the origin of sound.

7. Explain any method by means of which the ticking of a watch may be made audible to a person at the other end of a large room.

8. What is an echo? What is essential for the production of a single, and what of a multiple, echo?

9. How could you prove, by experiments or observations, that, when sound is produced and heard at a distance, the air has not actually travelled to the point where the sound is heard?

10. How is it that sound is transmitted for long distances, by speaking-tubes?

11. How would you show by experiment that, when a bell rings, the metal is in motion?

CHAPTER IV

MUSICAL SOUNDS—PITCH—INTENSITY—QUALITY

Pitch.—Certain sounds are pleasant to the ear, and are called musical sounds.

Take the toothed wheel and fix it to the whirling-table, or use the humming-top (Appendix). Turn very slowly and hold a card against the teeth. At first we hear a number of taps ; as the speed increases a musical sound is heard ; this sound continues as long as the wheel moves steadily : as the speed changes, the sound changes. Turn the wheel very rapidly ; the sound becomes painful, and at length we are unable to detect it by the ear.

A musical sound is caused by regular vibrations. An ordinary person hears a sound when the vibrations are not less than 40 to the second, nor more than 20,000 to the second ; (compare light) ; others can detect sounds caused by vibrations above and below these limits.

In place of the toothed wheel use the siren (Appendix). Turn and blow through a piece of bent tubing, the end of which is pointed over one set of holes ; when the motion is very slow, a series of puffs is heard. As the speed increases a note is sounded ; it rises in pitch, and at length the ear is unable to detect it. As in last experiment a number of regular vibrations produces a musical sound.

Fix a knitting-needle in a vice and make it vibrate, change the length until a sound is heard ; the pitch does not change as it vibrates, although the intensity of the sound does. Does the needle vibrate a definite number of times in a second ? This is best shown with a long strip of steel (use a steel straight-edge) that vibrates more slowly than the short needle. Fasten a stiff bristle to the end of the straight-edge. Smoke a long piece of glass. Arrange that the bristle touches the glass, and make the rod vibrate (fig. 55) ; it traces a line across the glass as it vibrates. Move the

glass quickly ; a curve is traced, resembling the sinuous curve on p. 61, and the conclusion is that the rod vibrates with harmonic motion. Stretch a string slightly between two points and pluck it ; the string vibrates slowly, but no sound is heard. Tighten it and a sound is produced. Judging from the result with Savart's wheel and the

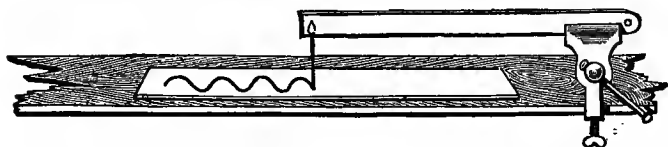


FIG. 55.

siren, the string, seeing that it gives a sound, should be vibrating regularly. Twist a pin round the stretched cord (wire) ; fasten it with sealing-wax so that the pin points horizontally ; pluck the wire vertically, and draw the smoked glass rapidly past the point. Examine the curve ; tighten the wire, and try again. The number of the vibrations increases as the pitch rises.

If we move the smoked glass with uniform speed, the wave-lengths traced by a vibrating body producing a certain note will be equal, they will decrease in width as the note dies away. The period of vibration of the body remains constant while the amplitude of the vibration diminishes.

A musical sound is produced by a body vibrating a definite number of times per second. The number of the vibrations determines the pitch of the note.

These vibrations are transmitted by the air to the ear. Suppose a string vibrates 560 times in a second ; at the end of one second the vibrating air-particles will extend from the string to a distance of 1,120 feet, as sound travels about 1,120 feet in one second. Therefore, each wave-length will be $\frac{1120}{560}$ feet, or 2 feet long. *The wave-length determines the pitch* ; the higher the pitch the shorter the wave-length.

The Musical Scale.—Attach the siren wheel (Appendix) to the whirling-table and turn steadily ; force air through a piece of glass tubing (one end bent at an angle of 135°) upon the inner row of holes, calling the sound heard Doh. Move the tube to the second row ; we recognise the Me of the musical scale. The third row gives the Soh, and with the outside row, the Doh', or octave, is heard. The

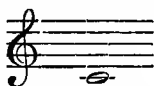
number of holes in the rows are as, 4, 5, 6, 8. Turn the wheel at a different rate ; when steady repeat the experiment. Again, if the first note be called Doh, the Me, Soh, Doh' are heard.

When the number of the vibrations per second is doubled, the octave of the scale is produced. If 400 vibrations per second give the fundamental note, 500 give the third, 600 the fifth, and 800 the octave.

The diatonic musical scale consists of seven sounds ; the note of lowest pitch is called the fundamental, and the eighth note the octave to the fundamental. By experiments similar to those performed, the relation between the vibration numbers of the notes of the scale has been found.

4		5		6		8	
24	27	30	32	36	40	45	48
Doh	Ray	Me	Fah	Soh	La	Te	Doh'
C	D	E	F	G	A	B	C'

The absolute value of C is immaterial ; it can be decided arbitrarily ; thus the C



is frequently taken as 256 ; it has been below 250 and as high as 270 ; the number 264 is in common use.

To find the vibration number of a vibrating body.—Suppose we take an ordinary whistle. A siren (of a more expensive form than that used in previous experiments), so constructed that it registers the number of turns per second, is required. Let us suppose the siren sounds the same note as that made by the whistle when it turns five times in a second, and that there are 96 holes. The vibration number of the whistle will be 96×5 , or 480 per second. Tuning-forks are stamped with their vibration number. Suppose the sound made by a fly moving its wings, is a fifth above a fork marked 264. The vibration number of the wings will be $264 \times \frac{6}{4}$, that is, the wings are vibrating 396 times in a second.

EXAMPLES. IV.

1. What are the physical differences (1) between a loud and a gentle sound, (2) between a shrill and a deep sound?
2. A bell when struck emits a note of a certain pitch. Is the wavelength in air corresponding to this note the same on a warm day as on a cold day? Give full reasons for your answer.
3. Taking 1,120 feet per second as the velocity of sound in air, find the number of vibrations which a middle C tuning-fork (which vibrates 264 times per second) must make before its sound is audible at a distance of 154 feet.
4. What are the three characteristics of musical sounds? How is the movement of the air-particles affected by (a) change of pitch, (b) change of intensity?
5. A tuning-fork is set in vibration and you hear its note. The sound is conveyed to your ear by the motion of the air-particles in the room. Explain how, and in what direction, the particles move, and state how their motion would be modified if the fork were made to give a louder sound.
6. Describe a method of determining the number of vibrations required to produce a note of given pitch.

Transverse vibrations of strings.—We have already produced sounds by causing strings to vibrate transversely, and have shown that the vibrations are made with harmonic motion. The large number of stringed musical instruments makes the study of vibrating strings important. An examination of a stringed instrument will give a general idea of the laws on which the pitch depends. In a violin the first string is thin, it is used to produce the high notes; the second and third strings are thicker, while the fourth string is made of wire. We infer that the thinner the string the higher the pitch, and the denser the material the lower the pitch. A player plays a higher note by shortening the length of the vibrating string, and we infer that the shorter the string the higher the pitch of the sound produced. If the note of a string be too high or too low, the player slackens or tightens the string to remedy the defect. We conclude that the greater the tension the higher will be the pitch of the note.

The Sonometer.—In order to examine the laws relating to strings, an instrument called a sonometer is used.

Two strings of the same material and thickness are stretched side by side ; they pass over the fixed bridges A and B, then over pulleys, and have equal weights attached to them (fig. 56).

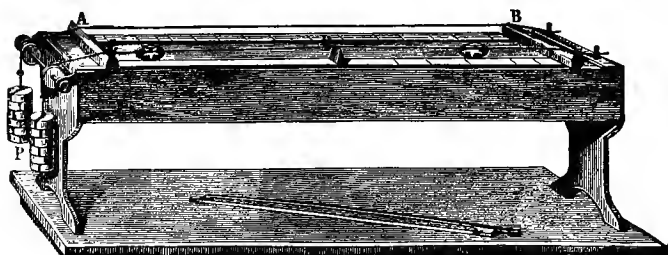


FIG. 56.

On plucking or bowing each string, notes of the same pitch are heard ; each string is vibrating as a whole, and is producing its fundamental note. Call this note Doh.

Insert one of the movable bridges D midway between the fixed bridges, so as to halve one string. Pluck one half and we recognise the octave. The octave is caused by twice the number of vibrations of the fundamental (p. 76).

By halving the length we have doubled the number of vibrations. By means of the movable bridges make one string two-thirds the length of the undivided string ; this length vibrating produces the Soh. That is, when the lengths are as 3 to 2, the vibration-numbers are as 4 to 6, or 2 to 3. Move the bridge until a length is found that on vibrating gives the Me ; it will be found to be four-fifths of the undivided string. Collect these results.

Length	Note	Vibration-number
1	Fundamental Doh	24 or 1
$\frac{1}{2}$	Third Me	30 " 5
$\frac{2}{3}$	Fourth Fah	32 " 4
$\frac{3}{4}$	Fifth Soh	36 " 3
$\frac{1}{3}$	Octave Doh'	48 " 2

FIRST LAW.—Other conditions being equal, the number of vibrations per second is inversely as the length of the string.

Use the full length of each string, and vary the stretching force. Attach 16 lbs. to each string, and add weights to one until on plucking, the octave is heard. You will find that the total weight is 64 lbs. That is, in order to double the number of vibrations we must quadruple the weights.

Verify your first law. On halving the stretched string with 16 lbs. attached, you should double the number of vibrations, and both strings should give the same note.

Begin again. Attach 16 lbs. to each string ; add weights to one until the Me is heard ; the weight will be 25 lbs. When the Soh is heard the weight will be 36 lbs.

Stretching force	Note	Vibration-number
16	Fundamental Doh	$4 = \sqrt{16}$
25	Me	$5 = \sqrt{25}$
36	Soh	$6 = \sqrt{36}$
64	Doh	$8 = \sqrt{64}$

SECOND LAW.—Other conditions being equal, the vibration number is proportional to the square root of the stretching force.

Combine the two laws ; stretch one string with a weight of 16 lbs., the other with 36 lbs. Move the bridge of the first until the same note is heard from both strings ; the length of the one will be two-thirds that of the other

$$\sqrt{16} \times \frac{1}{\frac{2}{3}} = \sqrt{36} \times \frac{1}{1}$$

The vibration-number also depends upon the thickness of the strings, that is upon the diameters ; this is not easy to verify, it being difficult to measure diameters ; careful experiments have shown the truth of the third law. If the diameter be doubled or trebled, the vibration number is divided by two or three.

THIRD LAW.—Other conditions being equal, the vibration-number is inversely as the diameter.

The fourth law refers to the density of the strings. If a

catgut string and a copper wire (length, diameter, and stretching force the same in both cases) be used on the sonometer, the copper wire gives the lower note. For this reason the fourth string of a violin, and the lower wires of a piano are wrapped round with wire, so as to increase their density.

Fourth Law.—The vibration-numbers are inversely proportional to the square roots of the densities.

	Densi- ties	Dia-me- ters or radii	Stretch- ing forces	Lengths	The vibration-numbers vary
If in 2 strings	X	X	X	O	Inversely as the lengths
„ „	X	X	O	X	Directly as the square roots of the stretching forces
„ „	X	O	X	X	Inversely as the diameter or radii
„ „	O	X	X	X	Inversely as the square roots of the densities

For X read 'are equal,' for O read 'vary.'

Quality of Sounds. Timbre.—Pluck one wire on the sonometer, it sounds its fundamental ; as it vibrates, touch it lightly in the middle with a thin roll of paper ; it ceases to vibrate as a whole, but on placing the ear near the wire the octave is heard.

The wire is vibrating in halves according to the First Law ; these vibrations have not been started by touching the wire, they were taking place while the string vibrated as a whole, and experienced ears can detect the octave, while a string is sounding its fundamental note. The wire may also divide into three portions, a note having three times the number of vibrations of the fundamental being produced. These notes sound at the same time as the fundamental.

While the fundamental note is sounding, other tones, called *harmonics*, are being produced ; these harmonics depend upon the character of the instrument.

The harmonics, combined with the fundamental, give the characteristic *quality* or *timbre* to the instrument.

Resonators.—The effect of thin pieces of wood and metal, in reinforcing the intensity of sound has already been noticed (p. 68) ; masses of air are used for a like purpose.

Take a glass tube a foot long and $\frac{3}{4}$ wide, open at both ends ; hold a vibrating tuning-fork over one end, and lower the other end into water ; at a certain depth the sound of the fork is suddenly reinforced ; if this depth be exceeded, the reinforcement ceases. Experiment with other forks, and notice that for each fork there is a definite depth of air in the tube of the resonator.

The prong of the tuning-fork *advances*, and sends a condensation down the tube, that is reflected at the surface of the water ; if the tube be of such a length that the reflected condensation reaches the prong just as it is about to spring back, the reflected condensation aids the prong in causing a greater condensation in its backward motion. The prong springs back and produces rarefaction behind it ; this rarefaction travels down the tube, is reflected, reaches the prong at its extreme limit and combines with it to produce a greater rarefaction. The effect is to increase the amplitude of the vibration of the air particles, and the intensity of the sound increases. It follows that the length of the simple tube will depend upon the number of vibrations made by the tuning-fork.

Name of fork	Vibration-number	Length of sound-wave (calculated)	Depth of tube (measured)
C	256	$\frac{1120}{256}$ feet = 52 inches	13 inches
G	324	$\frac{1120}{324}$ " = 35 "	$8\frac{3}{4}$ "

The depth of the closed resonator is one quarter of a wave-length. A wave-length is made up of a condensation and a rarefaction. As the prong of the fork advances, the condensation would travel twice the length of the tube if it were not reflected ; as the prong retreats the rarefaction would travel similarly twice the length of the tube ; the condensation would in this time have travelled four times the length of the tube ; the total condensation and rarefaction, or the wave-length, will therefore be four times the length of the tube.

The study of resonators becomes more complex when the diameter of the tube is great ; reflections take place from the sides.

The construction of wind instruments depends upon the resonance of air in the tubes, various methods being followed to set the column of air vibrating.

The increased loudness of a sound made in a room, compared with the loudness of the same sound in the open air, is due to resonance. The acoustic properties are good if the reflected sounds aid the original sound, and bad if the reflected sounds are not heard simultaneously with the original sound.

EXAMPLES. V.

1. A stretched string, 10 feet long, is in unison with a tuning-fork, marked 256 ; the string is shortened 4 feet : how often will it now vibrate in a second ?

2. A string is fastened at one end to a peg in a horizontal board, and the other end passes over a pulley and carries sixteen pounds. The string gives the note C. What weight must be hung instead of the sixteen pounds, so that the string gives the next lowest octave ?

3. Two equally stretched strings of the same thickness, one of steel and the other of catgut, give the same note when struck. Which of them is the longer ? Give reasons for your answer.

4. A steel wire, one yard long and stretched by a weight of 5 lbs., vibrates 100 times per second when plucked. If I wish to make two yards of the same wire vibrate *twice* as fast, with what weight must I stretch it ?

5. What variety of notes can you get out of a stretched string without altering its tension or length ? What will be the effect of halving its length by a fixed bridge ?

6. A musical string vibrates 400 times in a second : state what occurs when you make the length one-third and four times the original length without altering the tension ; and also what occurs when the tension is made four times and one-ninth the original tension, without altering its length.

7. The flash of a gun-cotton rocket, exploded at a height of 1,000 feet in the air, is seen by a person six miles distant. Some time afterwards the sound is heard. How many seconds elapse between the flash and the sound ? One thing which is purposely omitted ought to be taken into account. What is it ?

8. When a cannon is fired, windows are sometimes broken by the explosion. Why is this ?

LIGHT



CHAPTER I

RECTILINEAR PROPAGATION OF LIGHT—SHADOWS

Introduction.—The chief sources of light are the sun, the stars, chemical action, electricity, and phosphorescence. The light emitted by the glowworm or the firefly is an instance of phosphorescent light. Luminous bodies, such as the sun, a burning candle, and a glowworm shine by their own light. Non-luminous bodies are only rendered luminous and visible when in the presence of luminous bodies. Trees, houses, and furniture are examples of non-luminous bodies.

Transparent, translucent, and opaque bodies.—Bodies that allow light to pass, so that objects can be clearly distinguished through them, are called transparent : the air, water, and clear glass are common examples. Oiled paper, roughened glass, and porcelain allow light to pass, but objects cannot be clearly distinguished through them ; they are translucent bodies. Opaque bodies, such as gold and bricks, do not allow light to pass through them. Opaque bodies when very thin, are translucent, and transparent bodies, when very thick, become translucent and even opaque. When light passes through a transparent body, part of it is always absorbed.

Propagation of light.—A medium is a substance through which light passes, as air and glass. If the density and composition of the medium be the same in all parts, it is called homogeneous ; water, carefully prepared glass, and the atmosphere, if we consider only a small portion of it, are homogeneous.

In a homogeneous medium, light is propagated in straight lines ; this is our every-day experience. The rays of the sun, as they track their way through the room, are straight, and in order that light may pass through a tube, the tube must be straight.

Ray and Pencil of Light.—When light proceeds from a luminous body, it is supposed to be made up of straight lines, called rays of light. A number of rays form a pencil of light.

Place in the stage of the magic lantern a blackened card, with a hole $\frac{1}{8}$ " diameter in the centre ; focus this on the screen. Hold a piece of smouldering paper near, and notice the cone of light. Imagine this cone to be made up of an enormous number of rays.

Images produced by small apertures.—*A pinhole camera.* Make a large hole in the bottom of a coffee-tin, blacken the inside, and cover the hole with tinfoil ; construct a cylinder of cardboard that just slides inside the tin, and cover one end with tissue-paper. Make a pinhole in the centre of the tinfoil, push the covered end of the cylinder into the tin and look into it, pointing it to some illuminated object (trees, houses, &c.). By adjusting, an inverted coloured image is seen on the tissue-paper. Make another hole in the tinfoil, another image appears. As more holes are made, the images overlap, and become indistinct. Remove the tinfoil, the paper is uniformly illuminated.

In order to show this to a class, remove the objectives and condensers from a magic lantern, cover the aperture with a cap of tinfoil, prick one hole, and an image of the lamp-wicks is seen on the screen. By pricking more holes, the above effects are obtained.

That is, uniform illumination can be regarded as the result of a number of images overlapping each other.

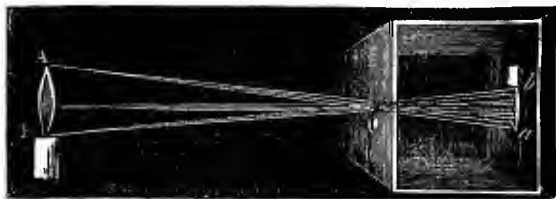


FIG. 57.

Light proceeds in straight lines from an object ; these lines cross at the small hole, and therefore the image is inverted.

Fig. 57 illustrates the formation of images through a small aperture.

The shape of the image does not depend upon the shape of the aperture, if the aperture be small.

Let sunlight enter a small triangular aperture made in the tinfoil of the camera ; by pushing in the inside tube, a *triangular image* is obtained. Darken the room, and allow the light from the sun, after passing through the aperture, to fall on a screen at some distance ; the image is *round*, or *elliptical* if we incline the screen.

Every point in the surface of the sun prints its own triangular image. When the screen is near the hole, these images nearly coincide, and a triangular image is formed. When the screen is moved away to a distance, the triangular patches are spread over a larger surface ; the overlapping of those in the middle of the space gives a bright patch, and the overlapping of those in the circumference forms a circular boundary.



FIG. 58

The circular and elliptical patches of light seen under a grove of trees are formed by the rays of sunlight passing through small apertures of varied shape formed by the overlapping of the leaves (fig. 58).

Shadows, Umbra, and Penumbra.—Light travels in straight lines, therefore part of the space behind an opaque body is protected from the light in front of it ; the opaque body casts a shadow. The section of shadow, that we receive on a screen, is generally spoken of as the shadow.

Hold a rod, 1'' diameter, vertically between a candle-flame and a piece of cardboard. You can arrange so that a sharply-defined shadow is obtained ; without changing the relative positions, turn the rod into a horizontal position ; the shadow is now indistinct at the edges. There is a dark central part, with a lighter part, on each side ; make pinholes in these parts ; go behind the screen and look through the pinholes at the candle. If a pinhole be in the darkest part, no part of the candle-flame can be seen ; if in the lighter part of the shadow, part of the flame can be seen. The darker part receives no light from the candle ; the lighter part receives part of the light of the candle.



FIG. 59.

The part of the shadow that receives no light from the luminous body is called the *umbra* ; the part that receives a



FIG. 60.

portion of the light from the luminous body is called the *penumbra*.

The size of the penumbra depends upon the relative sizes of the luminous and the opaque body. As the size of the source of light is reduced, the penumbra is reduced. If the luminous body be a point, there is no penumbra (fig. 59).

When the rod (p. 86) was held vertically, the width of the flame gave no appreciable penumbra; when the rod was horizontal, the long flame produced a distinct penumbra. If a luminous body, *ba* (fig. 60), be smaller than an opaque body *M*, the umbra, *no*, will always be surrounded by the penumbra, *rm*, and both will increase in size as the screen is moved away.

Eclipse.—The sun is larger, and the moon is smaller, than the earth. When the *umbra* of the moon falls on the earth, an eye placed in the umbra will be unable to see any part of the sun, and total eclipse is produced. Where the *penumbra* falls, there will be partial eclipse; part of the sun will be seen.

In fig. 61, *S* represents the sun, *M* the moon, and *E* the earth. The objects and distances are not constructed to the proper scale. Place a screen in the position of the earth, *E*, and examine the

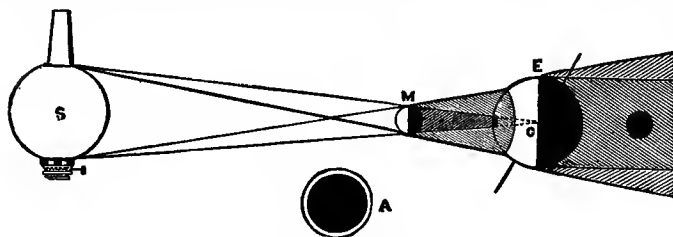


FIG. 61.

appearance of the lamp through pinholes from behind the screen; note particularly the crescent shape of the part seen. Move the screen away from *S*; beyond *C* all will be penumbra. A person in this penumbra will see a black circle, *A*, surrounded by a bright ring; an annular eclipse is produced.

If the moon pass into the shadows cast by the earth, the moon will be eclipsed—partially if it be partially in the shadow, totally if it be entirely in the shadow. We also learn that the moon is not self-luminous; it merely reflects the sun's light.

Intensity of Light.—The intensity of light is the quantity of light received on a unit of surface.

Place a square of cardboard, A (fig. 62), 1" side, one foot away from a candle, and a white screen 2 feet away. The shadow B measures 2 inches side. If A be removed, the light that fell on A (1 square inch) will fall on B (4 square inches).

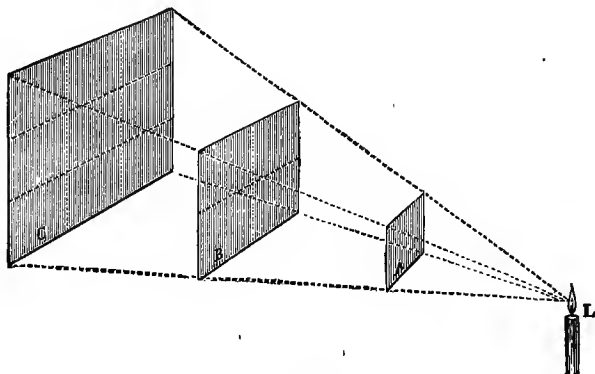


FIG. 62.

The intensity at B is one-fourth that of A. Similarly, the intensity at C (three feet away) is one-ninth that of A.

By doubling the distance the intensity becomes one fourth ; by trebling the distance the intensity becomes one-ninth.

If the screen in any position be inclined, the area illuminated is increased, and therefore the intensity of illumination is diminished.

The intensity of illumination varies inversely as the square of the distance from the luminous body.

The intensity changes with the inclination.

EXAMPLES. I.

1. If you make a pinhole in the bottom of a box, and replace the lid by a piece of tissue-paper, you see on the paper pictures of external objects. Explain the formation and character of the pictures.

2. When sunlight passes through the spaces between the leaves of trees, circular patches of light are seen on the ground. Why?

3. You cannot see the shadow of a hair held at a foot distance from a wall, against which the sun is shining; whereas you see the shadow when the hair is held close to the wall. What is the reason?

4. The centre of a luminous sphere $\frac{1}{2}$ " diameter, is 3" from the centre of an opaque sphere $1\frac{1}{2}$ " diameter. Sketch the shadow on a screen 6" from the centre of the luminous sphere.

5. Explain the terms pencil, ray, medium.

6. What is meant by the umbra and penumbra of a shadow? How could you show by experiment that from the penumbra, part of the luminous body can be seen?

7. A small ball is held before a luminous point; draw and describe the form of the shadow on the wall. Will there be a penumbra? Replace the luminous point by a luminous area. What effect will this have on the shadow?

8. Describe and illustrate a total eclipse of the sun. A person sees a partial eclipse; is he in the umbra or penumbra of the shadow?

9. The outline of the umbra of the earth on the moon in an eclipse is always circular. What information does this give regarding the shape of the earth?

10. Suppose light proceeds from a luminous point 12" distant from a screen: a piece of square cardboard 4" side is held parallel to the screen, 4" from the luminous point. Find the area of the shadow.

11. In No. 9 the screen is inclined to the cardboard; how does this affect the area of the shadow?

Photometry.—The law of inverse squares leads to a useful result.

THE SHADOW PHOTOMETER.—Take a cylinder of wood 18" high, and 1" diameter, a square of white cardboard 2' side, a lamp or gas flame, and a candle. Place the cylinder near the screen, and the candle at a distance of 18" from the screen. The lamp-flame should be the same height as the candle-flame. Move the lamp until the shadows of the cylinder appear side by side equally dark, and therefore equally illuminated (fig. 63, A).

The candle illuminates s_1 , and the lamp illuminates s_2 . The quantities of light received at s_1 , s_2 (fig. 63, B) are equal. By the law of inverse squares, the illuminating power of the lamp is to the illuminating power of the candle as the squares of their distances from s_2 and s_1 .

In an experiment $L_2 s_1$ was 12", and $L_1 s_2$ was 30"; therefore the light of the lamp was to the light of the candle as the

square of 30 to the square of 12—that is, as $6\frac{1}{4}$ to 1. The light of the lamp was equal to that of $6\frac{1}{4}$ candles.

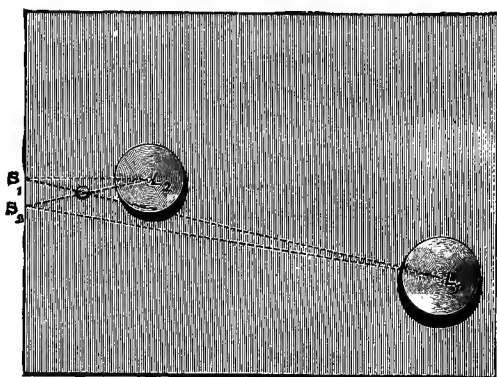
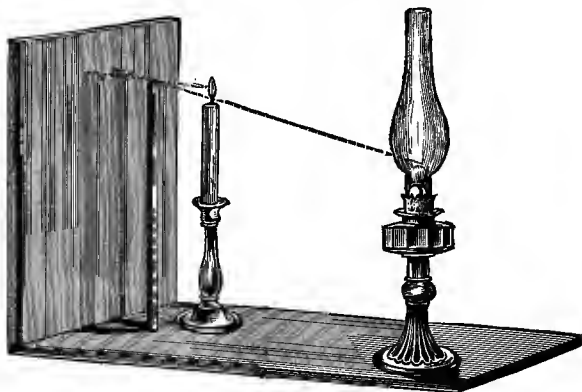


FIG. 63.

BUNSEN'S GREASE-SPOT PHOTOMETER.—A circular piece of writing-paper, stretched on a simple frame, has a small grease-spot made in the centre with a drop of wax from a candle. When both sides of the paper are equally illuminated the spot becomes invisible.

Arrange a gas flame or lamp, a candle, and the photometer, on a divided scale. Move the photometer till the spot disappears (fig. 64).

Example : the candle is 15" and the gas-flame 45" from the photometer. The gas-flame being three times the distance away that the candle is, the illuminating power will be 9 times that of the candle.

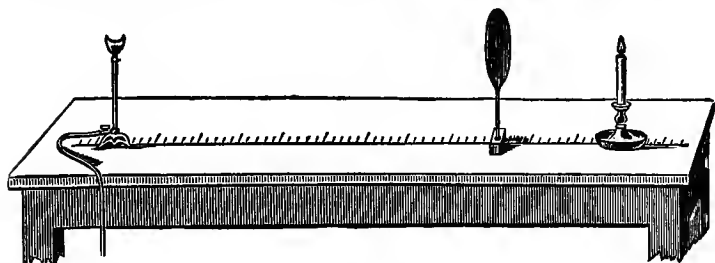


FIG. 64.

In gas reports, the standard candle is a sperm candle, 6 to the pound, burning at the rate of 120 grains in an hour.

To verify the laws of inverse squares.—Cut a piece of tin the shape of fig. 65, B; turn up the edges at the dotted lines, and make five holes, *a b c d e*. Place tacks through *a b d e* from the other side

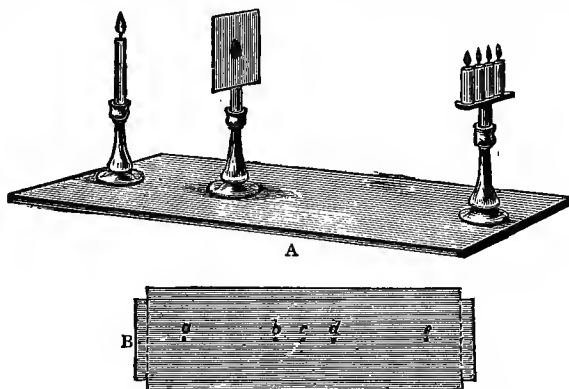


FIG. 65.

and solder them; fasten the tray to a rod by passing a tack through *c*.

Cut five pieces of candle from the same candle; place four of them on the tacks in *a b d e*, the fifth on a single stand; trim carefully, so that the wicks are all the same size and height; place four on

one side of the grease spot photometer, and the single candle on the other side. Find the distances at which the spot disappears.

The four candles should be at twice the distance of the single candle from the screen. In a similar manner use the five candles with the shadow photometer.

EXAMPLES. II.

1. Describe an experiment, made with the shadow photometer, to test the illuminating powers of two sources of light.

2. State, and explain, the relation between the intensity of the light, which falls on a given surface, and the distance of the source of light from the surface.

3. Of two gas-flames, one gives out 25 times as much light as the other. If you test their illuminating powers by means of a Rumford's (shadow) photometer, and you place the smaller flame at a distance of two feet from the screen, at what distance from the screen must the larger flame be placed in order that the shadows of an opaque object cast by the two flames may be equally illuminated?

4. Explain the principle of the Bunsen (or grease-spot) photometer. How would you prove that the illumination of any surface is inversely as the square of its distance from the source of light?

5. In fig. 62 if A be a disc 2" diameter, 3" from the luminous point, what shape and size will the shadow B be, when it is 7" from the point?

CHAPTER II

REFLECTION OF LIGHT. MIRRORS

Reflection of Light.—When light falls upon a piece of looking-glass or bright metal, the light is reflected.

L is a piece of looking-glass 1" side (fig. 66). A thin rod (a straw answers as well), represented by No, is fastened perpendicularly to L with white wax. A beam of light is deflected by a mirror, M, so that it strikes L at the foot of the rod; it is reflected in the direction NR. A cardboard semicircle of 1 ft. radius is divided into degrees. It can always be so arranged that the rays MN and NR, and the rod No lie in the plane of the semicircle. Measure the angles ONM and ONR in various positions; they are always equal. In order to observe easily the path of the rays hold smouldering paper near the path of the beam, and read the angles from o.

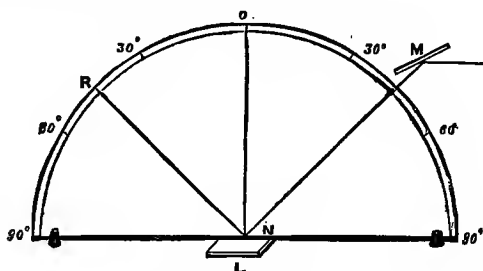


FIG. 66.

The ray that strikes the glass, is called the *incident ray*; the ray that is reflected, the *reflected ray*. A line perpendicular to a surface at a point, is called the *normal* at that point; it is represented by the line No.

The angle MNO, which the incident ray makes with the normal, is called the *angle of incidence*. The angle RNO,

which the reflected ray makes with the normal, is called the *angle of reflection*.

We conclude that—

(1) The angle of incidence equals the angle of reflection.

(2) That in whatever position the incident ray meets the mirror, a plane (the sheet of cardboard for example) can be so placed that it passes through the incident ray, the reflected ray, and the normal.

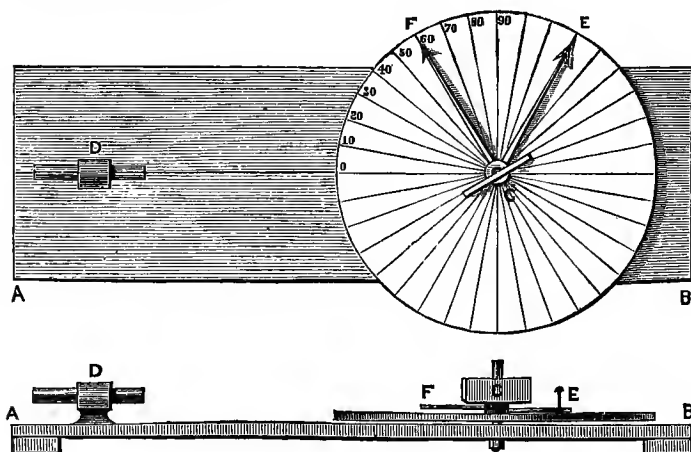


FIG 67.

A rotating mirror.—AB (fig. 67) is a deal board $12'' \times 4''$. A line CD is drawn upon it parallel to the sides. A cork is glued at A, and a piece of glass tubing $\frac{1}{2}''$ diameter, D, is passed through the cork so as to be parallel to the line; two threads are stretched vertically and horizontally across the end nearer to the mirror, so as to cross in the centre. A movable divided circle made of cardboard $6''$ radius is centred on the line. Two movable arms, E and F, of thin rod are movable on the same centre. To F is attached a piece of looking-glass C so that it stands vertically with its reflecting face at the centre. F is the normal to the glass. On E, at radius distance, fix a pin with a bright head. Place the mirror in any position; move the circle so that F is at 0° . Move the arm until the image of the pin-head seen by looking through the tube is at the intersection of the threads. As before, the angle FCE equals the angle FCD.

Turn the mirror through 10° , the motion is shown by F. Move E until its image can be seen; it must be moved through 20° . Turn the mirror through 5° , 20° , &c., and repeat. The motion of the pin is always twice that of the mirror.

If a mirror be made to rotate, the reflected beam moves through twice the angle passed over by the mirror.

Light is in itself invisible.—The rays of the sun are seen on account of the particles of dust in the air, which, reflect the light. The following experiment illustrates the invisibility of a beam of light.



FIG. 68.

The objectives of the lantern are removed and a black card with a circular hole in the centre is placed in the stage; this is focussed with the loose lens (fig. 68). Interpose a mirror and reflect the beam vertically into a glass jar covered with a glass plate. Notice how feeble the illumination is. Drop a piece of smouldering paper into the jar; as the smoke forms, the jar seems filled with diffused light. Remove the plate; as the smoke disappears streaks of darkness appear. If the jar be filled with distilled water, the beam is scarcely apparent; on adding a little milk the path is distinct. (A sunbeam through a hole in the shutter will answer better than the lantern beam.)

Although the particles of smoke are black, the reflected rays are white. The moon at its surface is dark, yet it appears to us white.

Regular and Irregular Reflection—Diffusion.—In an otherwise darkened room, allow sunlight, or a lantern beam, to fall in succession upon a piece of looking-glass, a sheet of tin, a sheet of

white cardboard, and a sheet of blackened cardboard. From the looking-glass a distinct spot of light is obtained on the wall, and the surface of the looking-glass cannot easily be seen. The sheet of tin gives a fairly distinct spot; its surface can be seen more readily from any part of the room than that of the looking-glass. The sheet of white cardboard gives no distinct spot; but its surface can be seen distinctly from any part of the room. The black sheet of cardboard does not reflect light.

Mirrors, and polished sheets of metal, are called good reflectors, they reflect light in a definite manner; their surfaces are smooth. Sheets of cardboard reflect light irregularly; the rays are diffused and are able to strike the eye in any part of the room; in a similar way the trees, furniture, diffuse the light that falls upon them, and become visible to us. Blackened cardboard and similar bodies absorb the light and appear black; they are bad reflectors.

The surfaces of highly-polished mirrors are seen with difficulty, they only become visible on account of the few rays diffused; similarly while we see distinctly the images reflected in the *smooth* lake we do not see the surface of the water; if, however, the surface becomes broken by a ripple, rays are diffused and we see the water itself.

Plane Mirrors.—Mirrors are made of polished metal or of smooth glass backed by an amalgam which gives a good reflecting surface. When the surface is a plane, such as an ordinary looking-glass, they are termed plane mirrors.

If a pencil of light, AB , from a luminous object A , from any cause be deflected and enter the eye in the direction BC , the luminous object *appears* in the prolongation of CB , that is at a (fig. 69).

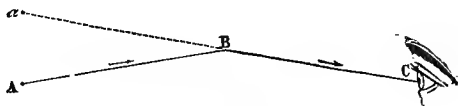


FIG. 69.

If a luminous point a (fig. 70) be placed in front of a plane mirror ss , rays will strike the mirror *in all directions* from a and will be reflected according to the laws of reflection; a

few such rays are drawn; the normals are dh , cg , &c. The reflected rays dm , cl , &c., all *appear* to come from a' , a point on the perpendicular ab produced, as far behind the mirror as a

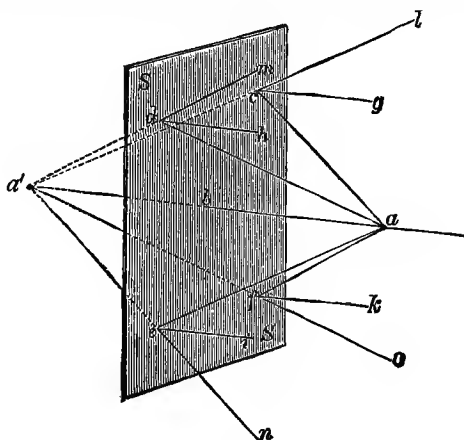


FIG. 70.

is in front. a' is called the optical image of a . Usually only a section of the mirror is shown, as in fig. 71.

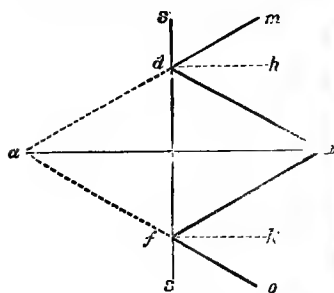


FIG. 71.

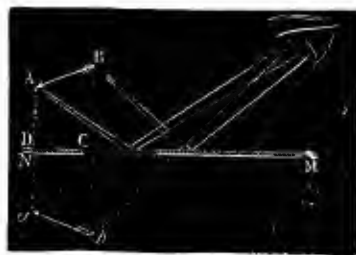


FIG. 72.

To draw the image of an object AB.—All bodies are made up of points, and the image will be the image of an assemblage of points. The image of A (fig. 72) is first obtained ($Da=DA$), then the image of B : the images of intermediate points will lie between a and b . It is also plain, that by doubling $CDA B$ over

on $cdab$, the figures will coincide, that is, the image is the same size as the object. Only a small portion of the surface is concerned in reflecting the rays; a person standing upright can see a complete image of himself in a looking-glass one half his height; the student can prove this by the aid of a diagram.

The images in plane mirrors have no actual existence, the rays of light only appear to come from them; such images are called *virtual images*.

The course of the pencil of rays is traced from A and B to the eye. The rays appear to the eye to come from a and b .

Lateral Inversion.—As we stand in front of a plane mirror, our right hand appears as the left hand of the image, this is termed ‘lateral inversion.’ As a result of this, if we write on paper, blot it, and hold the blotting-paper in front of a mirror, the writing can be read.

Inclined Mirrors.—Take two square pieces of looking-glass (about 1 foot side); varnish the backs, or cover them with card-

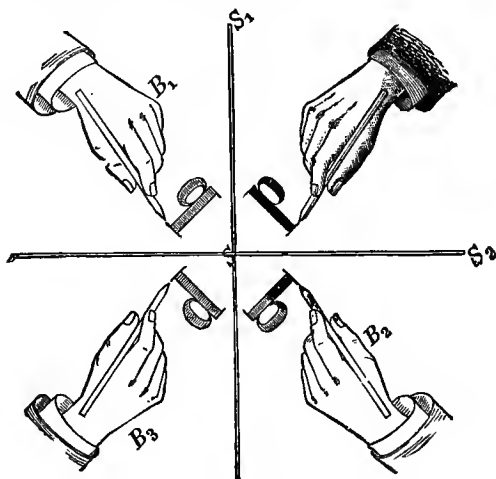


FIG. 73.

board. Join two edges with paste and black ribbon, so as to make a hinge. In fig. 73, SS_1 , SS_2 , are the horizontal sections of two mirrors,

at right angles to each other, each standing upright on a sheet of white cardboard. Print the letter 'p' as in the figure.

The letter is reflected in the mirror SS_1 at B_1 , and in the mirror SS_2 at B_2 . The image B_1 is reflected in the mirror SS_2 , and the image B_2 in the mirror SS_1 . If the hinge be a good one, an image B_3 will be seen. Draw the above with mathematical instruments, applying the laws of reflection. The images of B_1 in SS_2 and B_2 in SS_1 coincide, so that only one image, B_3 , results. Notice the lateral inversion in B_1 and B_2 , but that there is no lateral inversion in B_3 .

Arrange the mirrors so that they form an angle of 60° . Count the images and draw the figure. For simplicity a luminous point A is shown (fig. 74). In the experiment use a candle flame.

The images coincide at A_5 . The path of the rays by which A_4 is seen is drawn. A is reflected in SS_1 as A_1 . A_1 is reflected in SS_2 , as A_3 , &c.

As the angle between the mirrors diminishes, the number of images increases. With two parallel mirrors an infinite number would be seen, if light were not absorbed, reflected, and diffused. Practically a series is seen, whose brightness becomes fainter and fainter, until the distant images become invisible.

The Kaleidoscope is an instrument, made by placing two strips of glass in a tube, so that they are inclined at an angle of 60° ; one end of the tube is closed by a piece of roughened glass; on this is placed pieces of bright coloured glass and beads, kept loosely in their places by a sheet of plane glass. On looking in at the other end, and holding the tube to the light, various coloured images are seen, formed by reflections in the inclined mirrors.

Transparent bodies, such as unsilvered glass, can reflect

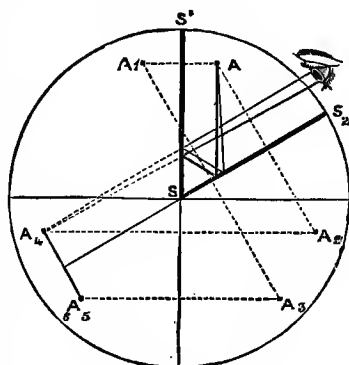


FIG. 74.

light. On looking at a window-pane obliquely, we see the objects outside the room, and also the images of the curtains and furniture inside the room. This mixing of objects and images is the principle of most ghost experiments.

Reflecting Power of Bodies.—The reflecting power varies in different reflectors, and also varies with the angle of inclination. Still water reflects 18 rays out of 1,000 when the light falls perpendicularly, 333 rays when it makes an angle of 80° with the normal, and 721 rays when it makes an angle of



FIG. 75.

$89\frac{1}{2}$ with the normal ; the remaining rays are either absorbed or are reflected irregularly. By holding a sheet of foolscap near a flame and looking at the paper obliquely, an image of the flame can be seen produced by the dull surface of the paper.

The image of the house (fig. 75), reflected by the still surface of the water, is formed according to the laws of reflection. If we be far above the surface of the water, or so situated that the reflected rays reaching the eye, make a small angle with the normal, we are frequently unable to see the reflected images. The reason is, the incident rays make a small angle with the normal, and too few of them are reflected to affect the eye.

The light seen on the clouds morning and evening, is another illustration of reflection, the rays are unable to reach us direct, they strike the clouds obliquely, and affect our eyes after reflection.

The image seen in smooth water, is equal in size to the object ; the surface acts like a plane mirror. When the water is thrown into ripples, it represents a large number of surfaces, inclined at various angles to us ; instead of one image, we see many, formed by the various surfaces, these become blurred and by running into each other, form an indefinite lengthened image, that is, in reality a combination of a number of images. The effect is best observed at night, when the object is a powerful light or the moon, and we see a track of light. Every little wave between the observer and the object has some part of it so inclined that it reflects momentarily the luminous object. Rays from the object strike other parts of the surface, but are not reflected so that they reach the eye ; these parts thus appear comparatively dark. If the water be very much broken, the rays are irregularly reflected, and we see no distinct image.

It has already been shown that it is difficult to see the surface of a good reflector ; if an opaque body cast a shadow on such a reflector, it is difficult to see the shadow. The opaque body cuts off the rays, that would be diffused from the part of the surface occupied by the shadow, but these being few in number, there is no appreciable difference between the number of rays that reach the eye from the shadow, and from any other equal surface of the reflector, that is, the shadow on the surface is not seen. If such a surface (a mirror for example) be covered with dust, more rays are diffused, and the absence of these rays from the shadow portion, is distinctly observable.

EXAMPLES. III.

1. Is the expression ' I see a sunbeam ' scientifically correct ?
2. A person sees his image, in a looking-glass inclined to the floor at an angle of 30° . Show by a drawing the size and position of the image.
3. A person is equidistant from two plane mirrors, which meet in the corner of a square room. Explain in what way the image of himself,

which he sees when looking towards the corner of the room, differs from the images which he sees when looking towards the sides of the room.

4. I stood yesterday beside a muddy lake with the sun behind me. My shadow was thrown distinctly upon the water. I stood afterwards beside a clear, deep lake, with the sun likewise behind me, and saw no shadow. Explain these observations.

5. When the sun was overclouded, as I stood beside the muddy lake, my shadow disappeared; but the images of trees on the opposite bank of the lake did not disappear. Explain the reason.

6. What is meant by 'lateral inversion'?

7. A sunbeam passes through a darkened room: when the blackest smoke is caused to cross the beam it appears white to an eye placed in the darkness. Explain the effect.

8. When a plane mirror is turned about an axis in its own plane, explain the change of position of the image of a small object seen by reflection in the mirror, and point out its relation to the laws of reflection of light.

9. Explain by aid of a diagram how a person can see a complete image of himself, in a plane mirror one-half his height.

10. Smoke the outside of a glass tube. Cover one end with tinfoil and prick a pinhole in the centre of the tinfoil; look through the other end at a candle. Explain the formation of the concentric circles of light.

Spherical mirrors.—Curved mirrors are generally part of a spherical surface. If the reflection be from the internal part of the sphere, they are called concave mirrors, and convex if the reflection be from the outside of the sphere.

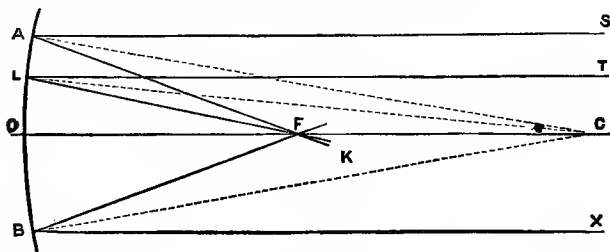


FIG. 76.

Suppose that AB (fig. 76) is the section of a concave mirror; c, the centre of the sphere, is called the centre of curvature, o the apex, and co the principal axis. A very small portion of the mirror at any point A will be a plane, of which A c, the

radius, will be the normal ; and if any incident ray, SA , strike the mirror at A the reflected ray will be AF (angle $SAC = \text{angle } FAC$) ; the same is true for any very small portion of the mirror as L, O and B . If the arc AB , the section of the reflecting surface, be small compared with the radius CO , it is found, both by measurements and experiments, that all incident rays, SA, TL, XB , &c., *parallel to the principal axis*, after reflection pass through the same point, F , in the principal axis. This point is midway between C and the mirror, and is called the **PRINCIPAL FOCUS** ; FO is the *focal length* of the mirror.

To find the focal length of a concave mirror.—The rays from a distant object are practically parallel (fig. 77).

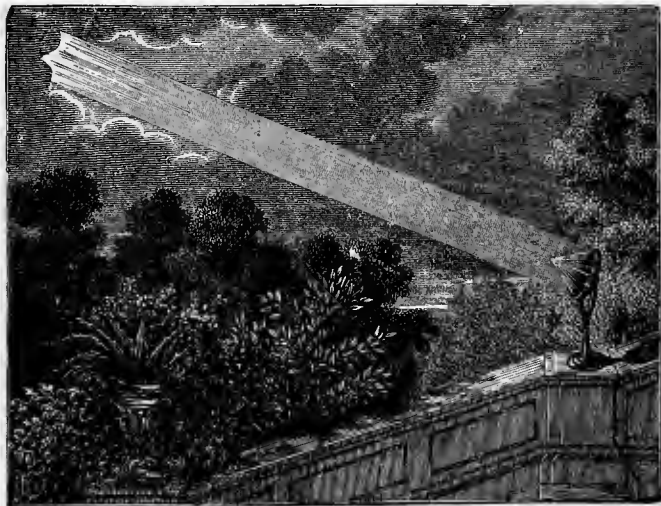


FIG. 77.

Hold a mirror so that the rays of the sun fall upon it and are parallel to its principal axis. Receive the image upon a small piece of ground glass. Measure the distance of the bright point (the image of the sun) from the mirror, this is the focal length. Heat is also reflected to the focus, and, if the glass be large enough, paper can be ignited. If the focal length of the mirror be small, a candle

20 or 30 feet away may serve as the distant object ; the image can be received on a small screen of tissue-paper fixed in a penholder.

The focal lengths obtained by these two methods will practically be equal. Concave mirrors are sometimes called 'burning mirrors' ; the reason for this name is evident.

The positions of the object and the image.—From fig. 76 we see, that if a luminous point be at *c*, all rays will be normal to the mirror, and therefore will be reflected back to *c*. When the object is at the centre of curvature, the image will be at the centre of curvature.

Arrange a mirror as in fig. 78. The line represents the principal axis. The screen is a square of cardboard. Place the candle as close as possible to the screen, the principal axis being between them ; and move the mirror until a distinct inverted image is obtained on the screen.

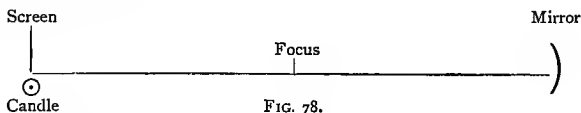


FIG. 78.

The distance from the candle to the mirror, is the radius of curvature, and therefore double the focal distance. The inverted image is equal in size to the object. A slight displacement of the candle up or down, causes a motion of the image down or up ; this is due to the object not being exactly on the principal axis, the rays thus come to a focus an equal distance from the principal axis.

If we place the candle as far away as possible, and then move it towards the mirror, we shall find that the inverted image, smaller

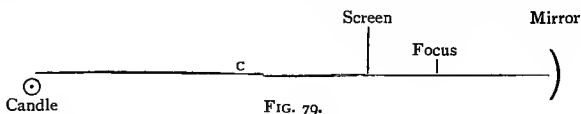


FIG. 79.

than the object, moves from the focus towards the centre (fig. 79), and increases in size as it approaches the centre, where the object and image are equal. Continue to move the candle towards the

mirror ; the image rapidly moves away and increases in size (fig. 80). As the candle approaches the focus we find that we are unable to obtain a good image. At the focus no image seems possible.

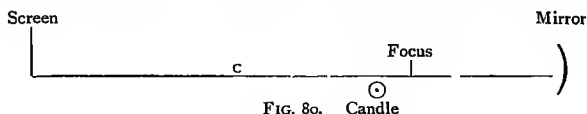


FIG. 80. Candle

If we remember that the focus is the intersection of parallel rays after reflection—that is, of rays from an object at an infinite distance—we shall conclude that the object has moved to an infinite distance. So far we have obtained an image upon a screen ; the screen is not essential, if we stand so that the image is between our eye and the mirror, and about a foot away, it can still be seen in mid-air, when we remove the screen of tissue-paper. The image is *real*, and with a hand-lens we can magnify it.

Move the candle from the focus towards the mirror ; no image is formed upon the screen, but we can see an upright enlarged image apparently behind the mirror.

This image, like the image formed by a plane mirror, is a *virtual* image.

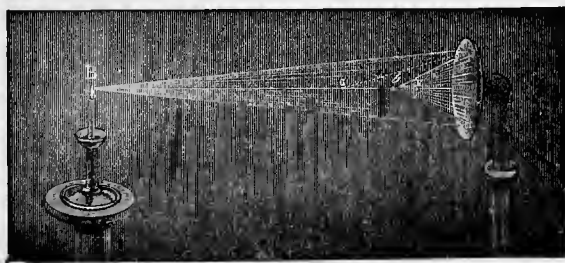


FIG. 81.

Whenever a real image is obtained, the image and object can change places. When the object is a point of light, the position of the image *b* (fig. 81) is called the conjugate focus of the object *B* ; if the candle were placed at *b*, then the image

would be at B. A good gas-flame answers even better than a candle in the experiments—the illumination is more powerful.

The distances of an object and its image, from a concave mirror, are connected by a rule that you should verify with some of your measurements.

The sum of the reciprocals, of the distance of the object and the image from a concave mirror, is equal to the reciprocal of the focal distance.

e.g. the focal distance of a concave mirror was determined by two methods to be 8 inches ; when the object was 40 inches from the mirror the image was 10 inches.

$$\frac{1}{40} + \frac{1}{10} = \frac{5}{40} = \frac{1}{8}.$$

When an object was 20 inches from a mirror, the image was 100 inches away. Find the focal length.

$$\text{Reciprocal of focal length} = \frac{1}{20} + \frac{1}{100} = \frac{6}{100}$$

$$\therefore \text{the focal length} = \frac{100}{6} = 16\frac{2}{3} \text{ inches.}$$

To obtain the positions of images by construction.—We may determine the position of an image by construction, because (1) rays parallel to the principal axis will after reflection pass through the focus; (2) any rays passing through the centre will

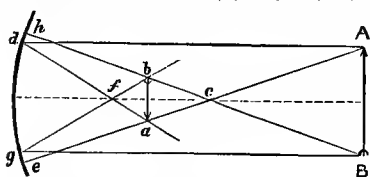


FIG. 82.

after reflection pass through the centre ; (3) all rays that pass through the focus will after reflection be parallel to the principal focus.

In fig. 82, A B, the object, is beyond the centre, c. The ray A d parallel to the principal axis is reflected through f, the principal focus, as d f a. The ray A c e after reflection returns through c the centre. These two rays intersect in a. All rays from A after reflection intersect in a, if the aperture of the mirror be small. a is the real image of A ; similarly b is the real image of B, and a b is the

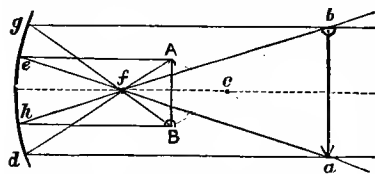


FIG. 83.

inverted, diminished image of A B. The image is real ; because the reflected rays actually pass through the image.

In fig. 83 the object is between the centre and the focus. The image is real, inverted, and enlarged.

In fig. 84 the object is between the focus and the mirror. The rays after reflection *appear* to come from $a b$. The image is *virtual*, upright, and enlarged. This shows how a concave mirror of great focal length can be used as a mirror in a room.

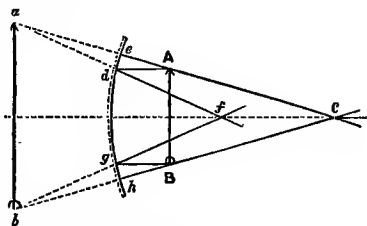


FIG. 84.

Use the same construction in all cases, and compare your results with those obtained by experiments.

Convex Mirrors.—The image is *always virtual*, upright, and smaller than the object.

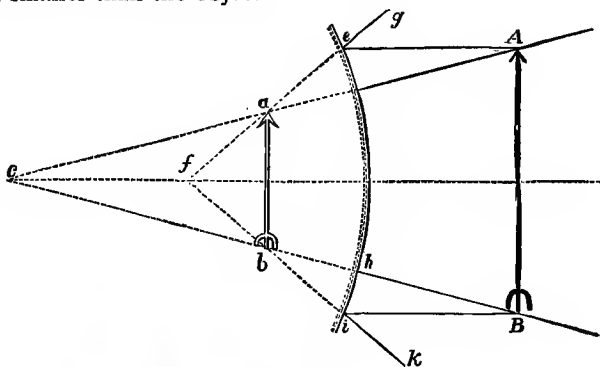


FIG. 85.

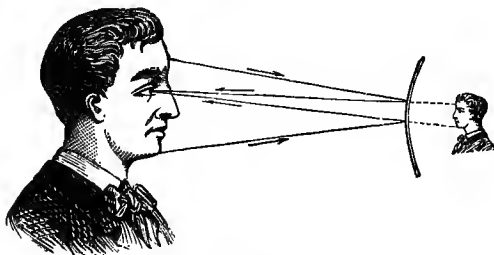


FIG. 86

Fig. 85 shows how the image ab may be obtained. The focus which is *virtual*, is determined by construction, as in the case of concave mirrors. A little consideration will show, that no matter how large the object may be, it is possible to produce an image of it, by the aid of a reflecting sphere; the image of the street and objects in it formed in the globular chemists' bottles will readily occur to the reader. Fig. 86 also illustrates the use of concave mirrors.

The Size of the Image.—In all cases of mirrors, *the size of the image is to the size of the object as the distance of the image from the mirror is to the distance of the object from the mirror.*

EXAMPLES. IV.

1. Where should a bright light be placed in front of a concave mirror so that the reflected rays shall be parallel?

2. Is the general effect of a convex mirror to cause divergence or convergence of incident rays? Illustrate your answer by a diagram.

3. The radius of a concave reflector is 20 inches; calculate the focal length. How would you find the focal length by experiments? Which method is the most accurate?

4. A gas-flame is 36' from a concave reflector; its image is clearly defined on a screen 50" from the reflector. Find the focal length and the radius of the mirror.

5. The radius of curvature of a concave mirror is 12" · a bright object is placed 18" from the mirror. Find the position of the image. Where will the image be when the object is 5" from the mirror?

6. Explain, and illustrate by a figure, the path of a beam of light from any source, which is reflected by a concave spherical mirror.

7. If you look at yourself in a convex spherical mirror you see an upright image. Under what circumstances can you see an upright image of yourself in a concave spherical mirror? What difference is there with respect to size, between the images seen in the two mirrors?

8. Explain, giving a drawing, how it is you see yourself as you do in a polished metal ball.

9. What is the difference between a 'real' and a 'virtual' image? Give a drawing, showing the formation of one of each kind.

10. Given a concave mirror whose focal length is 12 inches, where would you place a candle-flame, in order that the image of it, formed by the mirror, may be (1) real, (2) virtual?

CHAPTER III

REFRACTION OF LIGHT. LENSES

Refraction.—Place a coin at the bottom of a basin, and move the basin so that the coin is just hidden by the edge. Without moving the eye pour water into the basin ; the coin becomes visible (fig. 87).

The rays proceeding from the coin, are bent or refracted at the surface of the water, and the position of the coin appears to be raised. As a result of the refraction of the rays, the vessel—similarly ponds and rivers—appears shallower than it really is.

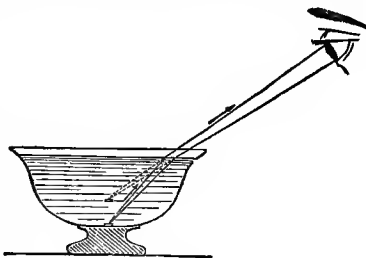


FIG. 87.

If a ray from L (fig. 88) meet the surface at A, by the above it will be refracted as AK ; LA is the *incident ray*, AK the *refracted ray*, BC the *normal* at A. The angle LAB is the *angle of incidence* ; and the angle KAC the *angle of refraction*.

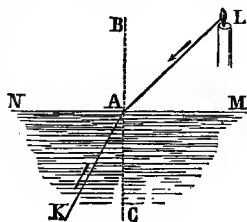


FIG. 88.

Fig. 89 represents a rectangular trough, $16'' \times 11'' \times 2''$, one end of glass, the rest tin. A circle, 5'' radius, is cut out of the front face and glass substituted. The strip on the top $18'' \times 2''$, is movable, and has two narrow slips cut in it. Blacken the tanks and the strips, draw the horizontal and vertical diameters, and fill with water to C. By a mirror, M, reflect a parallel beam through the slit, so that it meets

the water at C. The refraction of the beam is distinctly seen. You will not fail to observe that part of the beam is reflected as C R.

When light passes from air to a denser medium, part is bent towards the normal, and is refracted, part is reflected and part is absorbed.

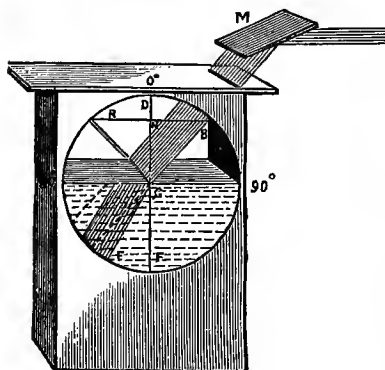


FIG. 89.

The law of sines.— $\frac{BN}{BC}$

is the sine of the angle of incidence, $\frac{EF}{EC}$ the sine of the angle of refraction (fig. 89). It is found that whatever the angle of incidence may be, the ratio $\frac{BN}{BC} \div \frac{EF}{EC}$ always gives the

same number—in this experiment as nearly as possible $\frac{4}{3}$. This number is called THE INDEX OF REFRACTION for air and water ; from air to glass it is $\frac{3}{2}$.

The laws of refraction are :—

1. The incident ray, the refracted ray, and the normal are in one plane.

2. The number obtained, by dividing the sine of the angle of incidence, by the sine of the angle of refraction, is the same for the same medium. This number is called the index of refraction.

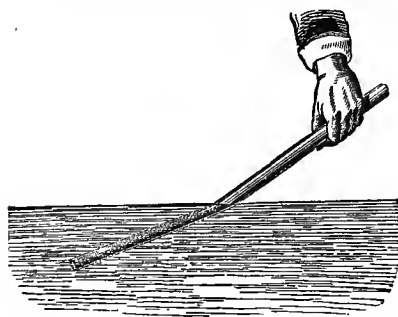


FIG. 90.

Some results of refraction.—A stick partly under water, seems to be bent at the surface ; the tip of the stick and all of it that is

under water appears to be raised (fig. 90). The rays from the part under water are refracted as in fig. 87.

The atmosphere is less dense as we ascend ; we can suppose it to be made up of layers. The rays of light from the sun or a star, instead of coming in straight lines, are refracted at every layer. Thus the light from *s* (fig. 91) reaches the eye as if it came from *s'* ; that is, a star appears higher in the heavens than its real position. For the same reason, the sun is seen before it is above, and after it is below the horizon.

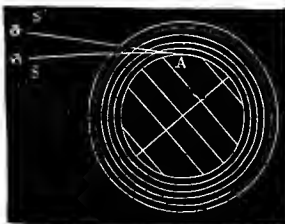


FIG. 91

Irregular refraction.—The rays of light are straight in air, and straight in water, provided the density be uniform. This is not the case, if from any cause the density be not uniform. The quivering of objects, when seen over heated coke or on a hot day, is due to unequal refraction ; the density is constantly changing.

Place a glass cell containing water in front of the lantern, and with a loose lens focus its image on the screen, so that the surface of the water is visible. If now you add a piece of ice, the cooled water sinks, a circulation of water at various densities ensues ; the result is the streaky appearance of the image on the screen. You may vary the density by adding syrup (heavier than water) alcohol or hot water (lighter than water). Focus a gas-flame or a red-hot poker on the screen, the shadow of the burning gas and the hot air will exhibit irregular refraction. If you use the heated platinum wire (page 3), and pass a current, similar effects are produced.

Total reflection.—A ray *LA* from water to air is refracted as *AR* (fig. 92) ; if we raise *L* higher, a point is reached when the ray *AR* just skims the surface *AM* ; if *L* be raised higher still, to *L'*, no light emerges ; the whole is reflected according to the laws of reflection, as *A r*. The angle which the incident ray makes with the normal, when the ray emerges parallel to the surface, is called the *critical angle*. The critical angle for water and air is $48\frac{1}{2}^{\circ}$. If you raise a glass of water above you,

you can easily find a position in which the rays from the eye, to every part of the under surface, make a greater angle than $48\frac{1}{2}^\circ$ with the normal. A brilliant mirror, due to the total reflection of light, is the result.

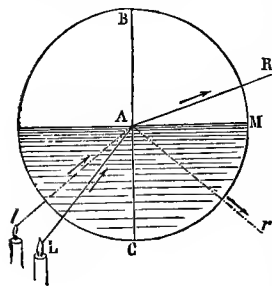


FIG. 92.

Transparent glass when finely ground loses its transparency, light is diffused at the surface, and the few rays that pass through the upper layer of fine particles, are refracted in passing from the glass to the air between the surfaces; the effect of this combined irregular reflection and refraction is, that the fine glass becomes opaque. If a liquid be poured over the glass whose refractive index is the same as that of glass, the result will be the same, as regards the action of light, as if the surface were made smooth and all the small spaces were filled with glass, that is, powdered glass becomes again a glass plate and is again transparent.

The mirage.—Under certain conditions, the layers of air nearest to the earth are less dense than those above. Light

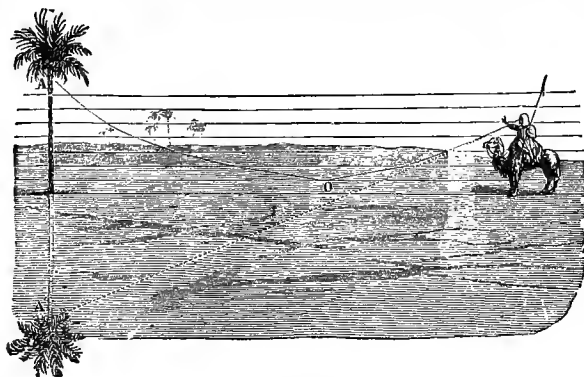


FIG. 93.

from A (fig. 93) is refracted *from* the normal; the refraction is repeated at each layer until at O the critical angle is reached,

and the ray becomes reflected; it is then refracted upwards *towards* the normal. The traveller sees A in the direction the ray reaches his eye, and it appears as at A'. The image may be seen, even when an obstacle prevents the object being seen by direct vision.

Refraction through a thick plate.—Hold a piece of thick glass obliquely, and look at an object, such as a post or window, so that part is seen through the glass, and part by direct vision. The object seems broken at the edge of the glass.

Let ab be a ray of light incident on a thick glass plate ss at b (fig. 94); the ray is refracted to c , and, again, on leaving the glass in the direction cd ; cd is parallel to ab ; the ray has moved to the left; an observer sees a , in the direction dce , if the ray pass through the plate, whereas if the plate be absent he sees it in the direction ba .

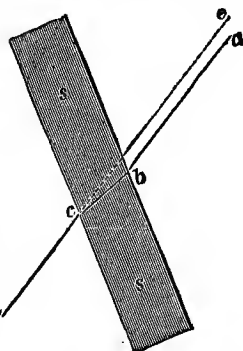


FIG. 94.

In the stage of the lantern after removing the objective, fix a blackened glass with a few upright lines scratched on it; focus with the lens the image on the screen. In front of the slide place a thick glass plate, so as to cover it half-way up. As long as the plate is parallel to the slide, the image is unbroken. Now turn the thick glass plate, so as to make an angle with the slide, keeping it vertical; the displacement of part of the image due to refraction, can be seen on the screen.

Multiple images seen in glass mirrors.—Place a candle near an ordinary glass mirror, and look at the mirror obliquely, several images can be distinguished.

The ray from A (fig. 95) meets the glass at b , part is reflected as bE , and the eye placed beyond EH sees the image at a . Part of the ray enters the glass, is refracted to c , the metallic surface; it is there reflected to d ; at d it is refracted to H ; the eye sees the image (the brightest image) at a' ; the ray

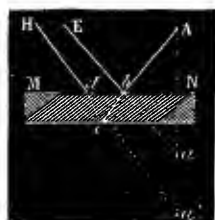


FIG. 95.

$c d$ is further reflected at d , and after reflection and refraction produces other images less distinct.

Incident light upon glass is broken up into reflected light (regular and irregular), the light that is absorbed by the glass, and the light that passes through or is transmitted.

EXAMPLES. V.

1. A candle is placed at a given small distance in front of an ordinary looking-glass, made of thick plate glass, quicksilvered on the back, and a person looking obliquely into the mirror sees several images of the candle. Explain this, and show the exact positions of the images by a diagram.

2. Explain clearly what you mean by the statement that the refractive index of water is $\frac{4}{3}$. How do you account for the appearance presented by a stick held in an oblique position, partly immersed in water, to a person looking at it sideways?

3. If you hold a glass of water with a spoon in it, a little above the level of the eye, and look upwards at the under surface of the water, you will find that you are unable to see that part of the spoon above the water. Explain this.

4. Explain why a fish seen in a pond, or in an aquarium tank, appears to be nearer the observer than it really is. Draw a picture to illustrate your answer.

5. You have a piece of thick plate glass, through which you look at a vertical pole (say a telegraph pole). The glass being held so that part of the pole is seen directly, and part through the glass, describe and explain the change in the apparent position of the part of the pole which is seen through the glass, when the latter is turned about a vertical axis.

6. A thick plate of glass is interposed obliquely between a candle and the observer's eye. Will the apparent position of the candle be altered by the glass. Draw a picture illustrating your answer.

7. Explain the images of a candle that are seen when a thick glass mirror is used; would they be seen in a polished silver reflector?

8. Account for the transparency of paper which has been soaked in oil.

Prisms.—Hold a prism in the hand, and look through it at a lighted candle (fig. 96); the candle seems raised; the ray $d e$ is refracted as $e h$ and $h k$, the eye sees the image of the candle at l .

The angle $d o l$ is called *the angle of deviation*; $b a c$ is the *refracting angle*, and A the *refracting edge* of the prism.

Make a small hole in the centre of a sheet of blackened card-

board (fig. 97). Place a candle in front, the wick being the same height from the ground as the hole. Receive the spot of light a

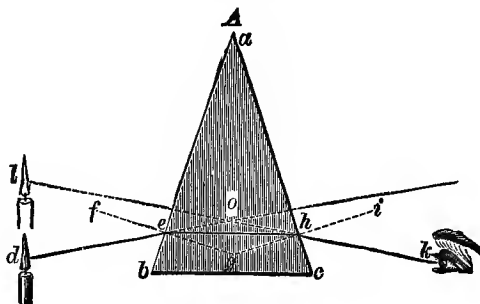


FIG. 96.

on a screen. Behind the hole place a prism with the refracting edge horizontal and parallel to the screen. The spot of light is moved to b , and by joining these two positions with the hole, the angle of deviation is practically found.

Remove the objectives and condensers from the lantern, focus a small hole in the cap with the loose lens on the screen; observe its position. Now place a wedge of glass (a prism) in the path of the rays;

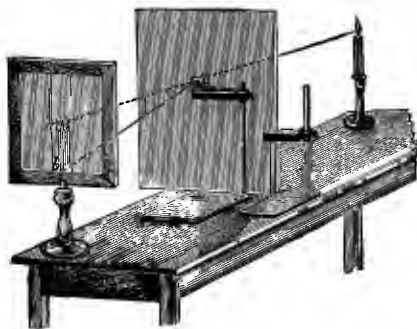


FIG. 97.

the spot moves towards the base of the prism, and the direction of the ray makes an angle with its former direction.

If you place a similar wedge base to base, the displacement of the spot of light increases. If they be arranged so as to form a plate, the emergent ray may be slightly displaced, but it will be parallel to its former direction; if the ray however meet the plate at right angles to the surface there is no displacement.

It will be found that the deviation is on the whole towards the base of the prism, and, as the angle of the prism increases,

the deviation increases. It also depends upon the substance. Flint glass produces a greater deviation than crown glass ; both act better than water. The angle of the prism must never exceed twice the critical angle, otherwise the rays do not get through. The critical angle for crown glass is 42° ; the refracting angle of a crown glass prism must not therefore be greater than 84° .

A lens acts like a number of prisms.—Suppose we have a number of small prisms, and we place the prism *b* (fig. 98)



FIG. 98.

with the largest angle, so that a spot of light, *a*, is refracted to *c*, then evidently if a prism *h*, exactly like *b*, be placed as in the figure, it also will refract the light to *c*. Join *a c*. By using *d* and *g* with smaller angles (less deviation) we can by trial find

positions so that they also refract rays from *a* to *c*. Similarly use *e* and *f*; finally between *e* and *f* we might place a plate of glass with parallel sides. Thus a number of rays from *a* can be made converge to *c*.

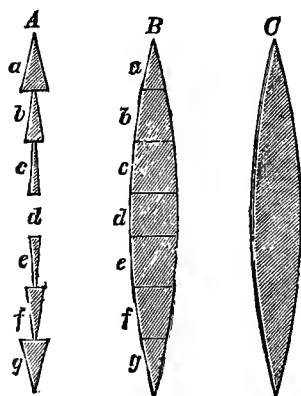


FIG. 99.

B, fig. 99, will have exactly the same effect as *A*, if the surfaces of *a b c . . .* in *B* be inclined at the same angles as the surfaces of *a b c . . .* in *A*.

Nature of a lens—A very large number of such prisms fitted together as in *B*, will form a body, whose section is *c*.

A body like c, when made of a refracting substance, is called a LENS, and it may be considered as being made up of a large number of prisms.

It is found that lenses whose surfaces are parts of the surface of a sphere act like the prisms in fig. 99, *if the surfaces be small compared with the whole surface of the sphere.*

The names given to the lenses (fig. 100) are: (M) Double convex—both surfaces convex; (N) Plano-convex—one surface convex, one plane; (O) Concavo-convex converging—one

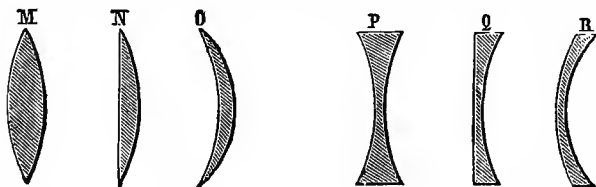


FIG. 100.

surface convex, one concave; (P) Double concave—both surfaces concave; (Q) Plano-concave—one concave, one plane; (R) Concavo-convex diverging—one concave, one convex. O and R are also called meniscus lenses.

Surfaces of lenses are usually parts of the surfaces of spheres of equal radii.—Fig. 101 shows how a double convex lens is formed. The student should construct figures for the other five lenses.

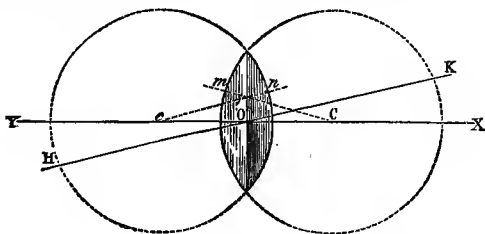


FIG. 101.

The line VX , passing through the centres, is the principal axis, Cn , Cm , as before, are the normals at n and m ; and C and C' are the centres of curvature. O is called the optical centre. The point where the rays parallel to the principal axis come to a focus, after refraction, is called the principal focus. (Compare 'focus' in mirrors.)

Hold the lenses so that the sunlight (parallel rays) falls upon them; find the focus (the point where an image of the sun is formed) on a piece of metal; measure the distance from the lens to the focus; this is the focal distance.

With M, N and O a focus is found ; they are converging lenses. With P, Q and R no real focus is found ; they are diverging lenses.

Find also the focus of rays from a distant object (the rays are practically parallel) and measure the focal length ; if the lens be of short focal length, the candle 20 or 30 feet away may serve as the distant object.

The object and the image.—**REAL IMAGES.** Place the candle as far away as possible from the lens, and obtain the focal length of the lens ; notice the small inverted image (fig. 102) obtained on

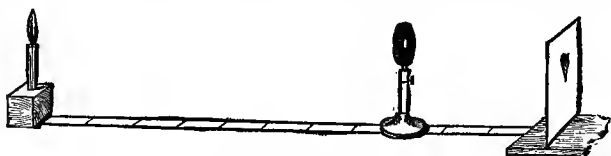


FIG. 102.

a piece of roughened glass or screen of tissue paper. Advance the candle towards the lens, the inverted image moves away from the lens.

At a certain position both image and object are equally distant from the lens, and both are equal in size. The distance between them is then four times the focal length—that is, both are twice the focal distance from the lens.

As the candle is moved yet nearer to the lens, the image rapidly becomes larger and more distant. When the object is at the principal focus, the image cannot be obtained.

The rays proceeding from the focus will be parallel after passing through the lens—that is, the image is at an infinite distance. In all these positions the image has been a *real image*, the rays after refraction actually pass through the image, and you can magnify it by using a hand lens. When the image is directly between you and the lens, and about a foot from you, remove the screen ; the image can still be seen, and in that condition can also be magnified.

VIRTUAL IMAGES. THE SIMPLE MICROSCOPE. If the object advance nearer to the lens than the principal focus, we

cannot obtain an image on a screen ; but if we look *through* the lens we see an image of the candle upright and enlarged ; the lens becomes a magnifying-glass or simple microscope. Any illuminated object $a b$ placed nearer to a convex lens than its principal focus F produces a virtual upright and enlarged image $A B$ (fig. 103).

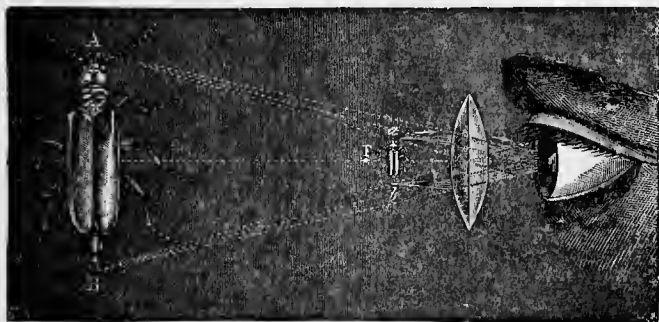


FIG. 103.

The astronomical telescope.—When we magnified with a convex lens the real images obtained on p. 118, we illustrated the principle of the astronomical telescope. The rays from the distant object $a b$, after refraction by the convex lens $c d$, give a real inverted image $a_1 b_1$ (fig. 104). By placing the lens

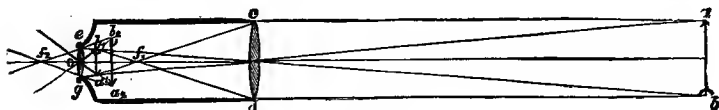


FIG. 104.

$e g$ of small focal length, so that $a_1 b_1$ is between this lens and its focus, the eye sees the virtual image $a_2 b_2$ upright as regards $a_1 b_1$, but inverted as regards the object $a b$. The large lens is called the refractor and the small lens the eyepiece. The inversion is unimportant in examining the heavenly bodies. In terrestrial telescopes other lenses are introduced in order to enable us to see the image upright.

To draw the image and objects.—The image can be obtained by remembering (a) that a ray parallel to the axis, after refraction passes through the focus, and (b) that a ray that passes through the optical centre does not undergo refraction.

1. *The object is at a greater distance from the lens, than twice the focal distance (fig. 105).*

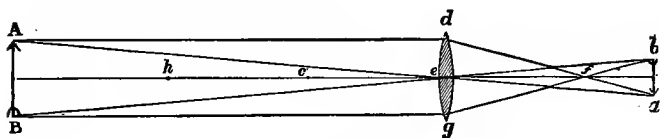


FIG. 105.

The ray $A d$ by (a) passes through focus f ; the ray $A e$ by (b) is not refracted; these rays meet in a . a is the real image of A . Similarly b is the real image of B . If the surfaces be small compared with the surfaces of the spheres, all rays from A and B will pass through a and b .

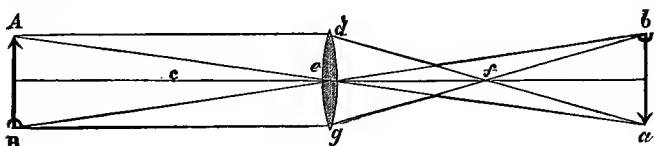


FIG. 106.

The image is real, inverted, and smaller than the object.

2. *The object is twice the focal distance, from the lens (fig. 106).*

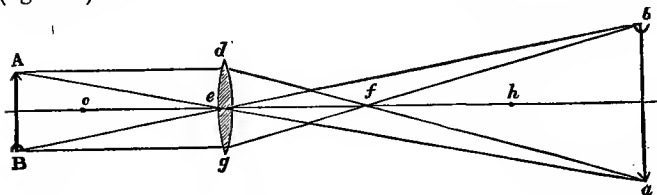


FIG. 107.

Use the same construction. The image is real, inverted,

the same size as the object, and an equal distance from the lens.

3. *The object is at a distance, less than twice the focal distance (fig. 107) from the lens.*

The image is real, inverted, at a greater distance from the lens, and greater than the object.

4. *The object is between the focus and the lens (fig. 108).* The rays A *d*, A *g* after refraction appear to come from *a*.

The image is virtual, erect, and larger than the object. This is the principle of the simple microscope. (See p. 119.)

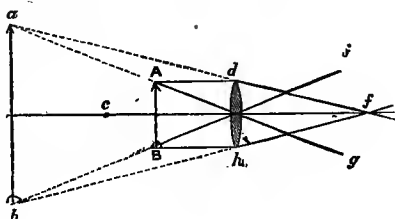


FIG. 108.

You will have noticed the analogy between the positions of image and object in connection with a convex lens and a concave mirror. In both the reciprocal of the distance of the object from the lens or mirror, added to the reciprocal of the distance of the image, gives the reciprocal of the focal distance.

Concave lenses.—The effect of a concave lens is to cause the rays to diverge after refraction. The lens is thinnest in the middle, and we can imagine it made up of prisms with their apices towards the centre of the lens. Parallel rays A *c*, B *h* (fig. 109), after refraction as *c d*, *h i*, appear to come from a point *f* called the *virtual focus*. Following the construction on page 120 it will be found that the rays from the object A B, after refraction, appear to come from *a b*, and produce a virtual upright image, less than the object.

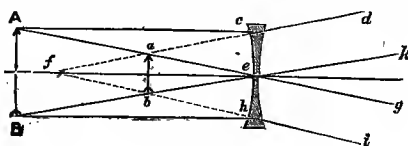


FIG. 109.

If we use a concave lens, and examine an object A B (fig. 110), we shall see an upright virtual image *a b*, smaller than the object; the image is generally very distinct, seeing that the

light from a large area AB appears to come from a small surface ab .

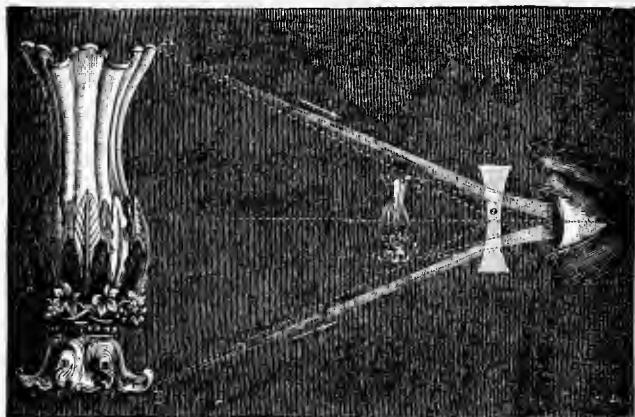


FIG. 110.

The Magic Lantern.—This instrument illustrates the uses of mirrors and lenses. A lamp-flame is placed, at the focus of a mirror M ; thus all reflected rays are parallel; these rays meet

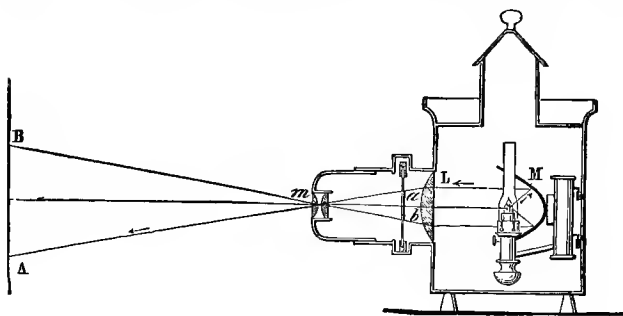


FIG. 111.

the convex lens L , called the condenser, and converge the rays to the focus of L . The movable lens m , called the objective, whether single or made of two lenses, acts like one convex lens. The converging rays pass through the slide ab ; ab is nearer

to m than twice its focal distance, hence an *inverted* real and enlarged image of the slide ab is formed on the screen ; for this reason magic lantern slides are put in inverted. BA is a real inverted, enlarged image of ab . The objective is moved until a clearly defined image is obtained. The use of the condenser is to throw as many rays as possible upon ab ; if L were removed, few rays, comparatively, would fall upon ab , and thus the illumination of AB would be feeble.

The Eye.—The principal parts of the eyeball, regarded as an optical instrument are : the transparent curved cornea in front, 2, (fig. 112) the crystalline lens, a transparent double convex lens, 4, and the retina lining the inside, being the expansion of the optic nerve, 1, coming from the brain. The crystalline lens divides the cavity into two parts, the smaller in

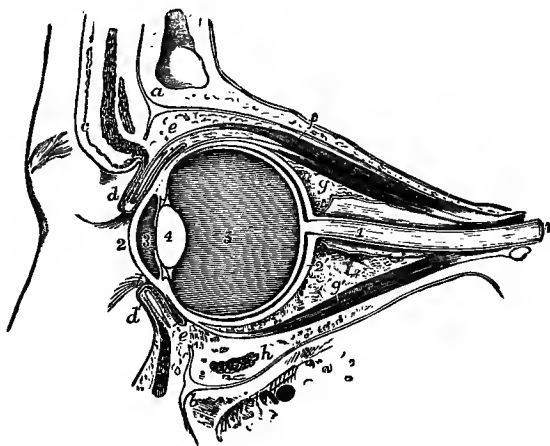


FIG. 112.

front, 3, is filled with a clear liquid, the aqueous humour, and the larger, behind, is filled with a clear jelly, the vitreous humour. A circular opaque curtain, the iris, in front of the lens, is perforated by a central hole, that forms the pupil ; the iris gives the colour to the eye.

Rays from an object, are refracted by the cornea and the lens ; they form a distinct inverted image on the retina, and the

impression is conveyed to the brain. The study of lenses has shown, that the distance of the image from the lens will change, as the distance of the object changes. The eye adapts itself by an alteration in the convexity of the crystalline lens, so that the image on the retina is, in a healthy eye, always sharp.

Short-sight. Concave spectacles.—In certain eyes the cornea and the lens are too convex, rays from an object M (fig. 113) come to a focus, m , too far in front for any possible

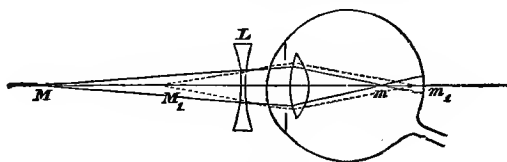


FIG. 113.

flattening of the lens to correct, the result is a blurred image on the retina. On bringing the objects nearer, to M_1 , the image recedes and forms clearly on the retina at m_1 . In order to remedy this *short sight*, a suitable concave lens is placed before the eye; this causes greater divergence of rays, producing a similar effect to bringing the object nearer to the eye.

Long-sight. Convex spectacles.—Long sight is caused by the flattening of the cornea and the lens, and is generally due

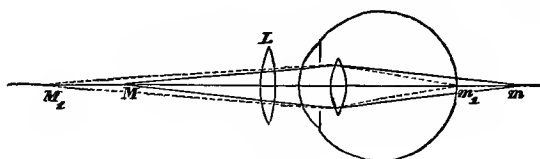


FIG. 114.

to age. The focus of an object M , at an ordinary distance (fig. 114) is behind the retina at m ; a distant object, M_1 , has, of course, its focus m_1 nearer to the lens, and is thus distinctly seen. A suitable convex lens L , causes the rays from M to converge, that is, they enter the eye as if they came from a distant object; the defect of long sight is thus remedied, and a book can be read, or near objects seen with ease.

EXAMPLES. VI.

1. Explain the different effects produced by a convex lens when it is used (1) as the object-glass of a telescope, (2) as a magnifying glass.

2. Explain the way in which a double convex lens is employed to obtain a magnified image of an object. What do you understand by the focal length of a convex lens?

3. On a sheet of paper placed vertically is written a capital L. If an observer stand 3 feet in front of the paper, and hold a double convex lens, of 6 inches focal length, half-way between his eye and the paper, he will see an image of the letter. Draw a picture of the image as seen, and state whether it is larger or smaller than the object.

4. State generally the effect of a lens upon a ray of light passing through it. Show how, with a double convex lens, an image of a lighted candle may be seen (1) inverted and magnified, (2) inverted and diminished, (3) erect and magnified.

5. A luminous object moves along the axis of a double concave lens. Trace the position and size of the virtual image.

6. Describe a method of determining the focal length of a convex lens. Explain the relation between the effects produced by a convex lens and a concave mirror of the same focal length.

7. Explain the formation of the image of an object by means of a concave spherical mirror. Compare a convex spherical lens with a concave spherical mirror of the same focal length, as regards its action on a beam of light.

8. Sketch and describe a magic lantern, showing the effect of the lenses.

9. Describe the astronomical refracting telescope.

10. What is long sight and short sight? How is each caused and how remedied?

CHAPTER IV

COLOUR

Analysis of light. The spectrum. In many experiments with prisms and lenses, the images are tinged with colour, reminding us of the hues of the rainbow. These colours are due to refraction.

In the following experiment you may use, as your pencil of light, sunlight streaming through a small hole in the shutter, or a beam from the lantern. To use the lantern remove the objectives, and place a cap on, in which is a small hole; focus this hole with a lens on a screen, and place the prism in the path of the rays.

There is refraction, but instead of one image we find a band of colour called the *spectrum*. The separation of white light into its component parts is called *dispersion*. The white light, in passing through the prism, has been decomposed, and we can distinguish in order, red (the least refracted of the rays), orange, yellow, green, blue, indigo, and violet (the most refracted).

Place a second prism similar to the one used, as in fig. 115, so that the faces are parallel. The light emerging from the second is no longer coloured. The second prism has recombined the colours and reformed white light. Slip a card in between them, so as to cut off the reddish rays; the rays E, are now coloured blue.



FIG. 115.

We conclude that white light is composite, that it is made up of coloured rays, and that of these rays, red is refracted the least, violet the most, while the others are intermediate. This has been proved by analysis by using the prism, and by synthesis

by the aid of another similar prism. A further proof by synthesis is afforded by the colour disc.

Divide a disc of white cardboard into fourteen equal sectors. Paint the sectors brilliantly in the following order : red, orange, yellow, green, light blue, dark blue, purple. Paint a black ring around the coloured sector, and a black ring in the centre. Fasten this colour-disc to a whirling table or top, or merely spin it on a pin stuck in the wall and let the sunlight or a lantern beam fall upon it.

The colours blend and grey light is formed. If the colours were perfect and the light strong enough, white light would be formed.

Fasten pieces of black paper over any of the sectors, say the blue ; spin and note the reddish tint ; cover the red and a bluish tint appears.

Colour is caused by suppressing colour, this was also illustrated when the card was interposed between the prisms (fig. 115) : red means the absence of blue from white light.

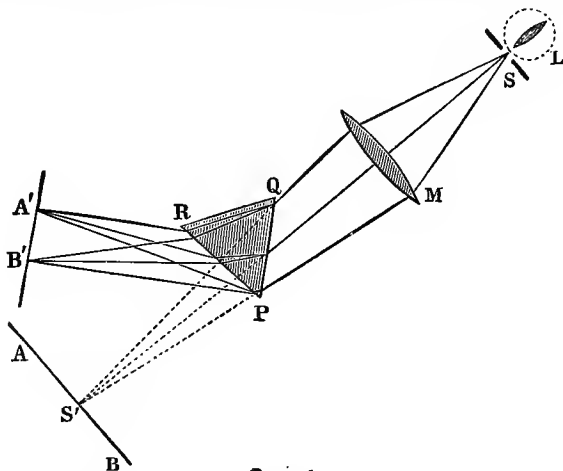


FIG. 116.

A carbon disulphide prism is better than one of glass, and a slit is preferable to a hole. Place on the lantern a cap with a slit $1'' \times \frac{1}{16}''$ and focus this on a screen. S (fig. 116) is the slit, M a convex lens focussing the slit at S'. Now interpose the carbon

disulphide prism P Q R. The spectrum is obtained at A' B'. Protect both the lens M, and the prism with sheets of blackened cardboard, to prevent the passage of stray light. Move the eye along the spectrum and look at the prism; in every position you see a coloured slit. Hold the coloured papers or ribbons in the spectrum; a red ribbon stretched along the spectrum appears black at the blue end, red at the red end: a blue ribbon is black save near the blue end. Coloured flowers appear to be colourless (black), unless they be placed in the proper part of the spectrum.

The spectrum is made up of a number of coloured images of the slit, and we conclude that the objects around us are coloured, because they only reflect part of the mixed white light; they reflect their own colour and absorb the remainder.

Even without a lantern, and independent of the direct sun's rays, the spectrum can be studied. Always, however, use the sun spectrum if possible. A piece of white paper $1'' \times \frac{1}{16}''$ placed on a black ground is viewed with a wedge of glass—a chandelier-drop. A small spectrum is seen. Put a similar red strip end to end with the white; only a red spectrum is seen, much smaller than the complete spectrum obtained from the white strip; the red spectrum is over the red end of the complete spectrum. With a blue strip, the blue end only can be distinguished over the blue end of the full spectrum. The blue strip, for example, reflects only the blue rays; these alone pass through the prism and are refracted.

Reflected, absorbed, and transmitted colours.—Cover the slit of the lantern with the blue glass; all the spectrum disappears, save the red end; if the red glass be used, the blue end is cut off. If both be used, no spectrum is seen. The coloured solutions placed in glass cells will give similar results.¹

Red glass is red because the rays at the red end of the spectrum alone are transmitted, the remainder being absorbed. With a pure blue glass only the blue end passes, the red being absorbed. If both be used no light passes, and we say the colour is black; more correctly, there is no colour.

If we reflect a beam of white light with pieces of coloured glass at a suitable angle, the reflected ray is white, just as the

¹ A good blue colour is obtained by dissolving sulphate of copper in water (1:10) and adding ammonia until the precipitate first formed is dissolved.

moon, in reality black, reflects the white light of the sun ; on turning a stick of red sealing-wax round, white light can be obtained reflected from part of the red wax. If the surface be rough, the light is reflected from particle to particle, they absorb part, and reflect the other rays of the spectrum, these meet the eye and cause the sensation of colour. A similar effect is produced if the rays enter for a small distance into a reflector, part of the coloured rays are absorbed, the remainder are reflected and are coloured. You may illustrate these statements by reflecting a lantern beam, from sheets of coloured paper, and pieces of coloured glass.

Evidently if light, instead of being made up of several colours, consisted only of one, shades of that colour alone would be seen. When salt is burnt in the wick of a spirit lamp, or in the colourless flame of a Bunsen burner, a pure yellow is obtained. Turn out all other lights and try this: red lips are nearly black, and all objects in the room are a shade of yellow.

Radiant Light and Heat.—Attention has been drawn to the fact that light and heat are reflected and refracted similarly ; mirrors and lenses have practically the same focus for each. Both are propagated by wave motion, the vibration being across the line of direction of the wave. In sound-waves the vibration of the air particles was in the line of direction (see p. 60). Between the smallest particles of matter, there is supposed to exist a medium called ether ; it is by the vibration of the ether spheres, that light and radiant heat are transmitted. The waves are of different lengths, that is, the periods of vibration of the particles differ. The longest rays cause the sensation of heat, next come the rays that cause the sensation of red colour, shorter than these are the rays that cause the sensation of orange colour ; as the rays become shorter the other colours of the spectrum are produced, the shortest of the light waves giving the sensation of violet colour. There are yet shorter rays than the violet, called *actinic rays* ; they do not however affect the eye as regards colour ; they are important in photography, from their power to affect chemical substances.

When a body is heated, it possesses energy (see p. 52), this

energy sets in motion the ether spheres, the first waves transmitted are the heat waves ; as the temperature of the body rises, the increased energy starts other waves ; first we have those that cause the sensation of red colour, the body is at red heat ; as the temperature further rises, shorter waves are started, the colour changes, until, when all the light waves are in motion, the composite effect is white light, the body is at white heat.

Ice transmits the light waves but absorbs the heat waves whose energy melts the ice. A solution of iodine in carbon disulphide absorbs the light waves—that is, no light passes—but transmits the heat waves. Red glass allows the long waves to pass, but absorbs the short waves.

A simple colour then depends upon the wave-length, that is, upon the period of vibration ; the intensity of such a colour depends upon the amplitude of the vibrations.

The wave-lengths are exceedingly small, there being 33,000 waves in an inch in a red ray, and 64,000 in an inch in a violet ray.

All rays are transmitted with the same velocity, the velocity of light and radiant heat being 186,000 miles per second.

EXAMPLES. VII.

1. If you hold one piece of glass up to the sun it appears dark red ; if you hold another up to the sun it appears dark blue. If you put the two glasses together you cannot see the sun at all through them. How is this ?

2. How would you disprove, experimentally, the assertion that white light, passing through a piece of coloured glass, acquires colour from the glass ? What is it that really happens ?

3. A lamp-flame, looked at through a glass prism, appears to be coloured blue on one side and red on the other. Draw a picture tracing the rays from the lamp to the eye, and showing which side of the coloured image is red, and which side is blue.

4. Explain, and illustrate by a figure, what happens to a ray of sunlight in passing through a triangular prism.

5. Why is it that, if you look at a white sheet of paper through a slab of glass held obliquely, one edge of the paper looks blue and the other red ?

6. Light enters a room through blue glass ; what appearance does a red coat present in such a room ?

7. Describe an experiment proving that white light is compound. How can it be shown that the constituents into which it is resolved are not likewise compound ?

MAGNETISM



CHAPTER I

MAGNETIC INDUCTION

Natural Magnets. Lodestones.—The ancients were acquainted with pieces of black iron-ore that had the property of attracting small pieces of iron and steel. These pieces of ore were found more especially at Magnesia, in Asia Minor, and were called magnets. It was afterwards discovered that, if suspended freely, they pointed north and south ; hence they were also named lodestones, that is leading-stones. Natural magnets are an oxide of iron.



FIG. 117

Dip a lodestone into iron filings ; the filings attach themselves to it and cluster thickly near the ends (fig. 117). The attraction is confined to iron and steel ; the natural magnet has no attraction for pieces of paper, sawdust, or pieces of wool.

Place the natural magnet on a stirrup suspended by a piece of untwisted silk. It sets in a direction nearly north and south (fig. 118).



FIG. 118.

Artificial magnets.—Dip a small piece of watch-spring or a needle, into fine iron-filings ; neither, if unmagnetised, will attract the filings. Rub both with the lodestone ; they are now magnetised and will attract the filings. Each is called an artificial magnet.

If the piece of steel be already magnetised, demagnetise it by making it red hot and cooling it in water.

Artificial magnets are magnetised by other methods, that will be given later. They are either straight bars of steel, and are called *bar magnets*, or are bent like a horse-shoe, and are then termed *Horse-shoe Magnets* (fig. 119).

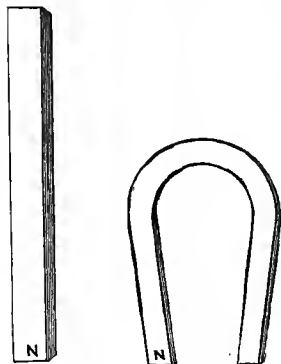


FIG. 119.

Repeat experiments similar to those made with the natural magnets, and show that the bar and horse-shoe magnets attract pieces of iron and steel, that they have no attraction for sawdust, pieces of paper, leaves, &c., and that when placed in the stirrup they set north and south.

The metals nickel and cobalt can also be magnetised. Magnetism is, however, chiefly studied in connection with iron and steel.

Methods of suspension.—It will frequently be necessary in experiments to arrange so that bars, magnets, &c., may be able to move freely in a horizontal plane. The following plans may be used :

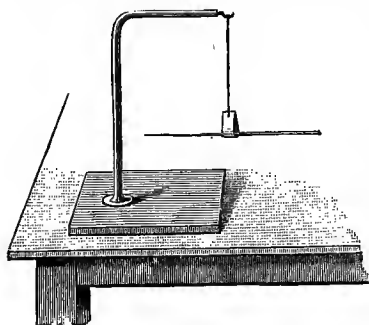


FIG. 120.

(1) Make a stirrup with copper-wire, and hang it to a support by fibres of *untwisted* silk, or by a horse-hair (fig. 118). A paper stirrup is also convenient (fig. 120). (2) Place the body on a piece of cork floating in water (fig. 121). (3) In ordinary magnets a hole is drilled through the centre of mass

of the needle, generally cut lozenge-shape, and a brass cap is inserted (fig. 122). In the better needles the top of the cap is made of agate. The cap rests upon the point of a fine needle ; the magnetic needle is balanced by filing one of the ends. A cheap needle can

be made thus :—Find as nearly as possible the centre of mass of a knitting-needle. Heat the needle to a red heat (preferably over a charcoal fire), and bend it into the shape of fig. 121. Again make it red-hot, and throw it into water, in order to temper it. Magnetise it with a permanent magnet (p. 142). Draw a piece of glass tubing out to a point, keeping it in

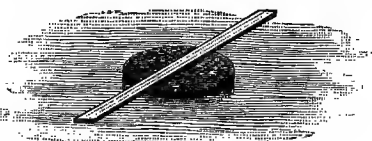


FIG. 121.

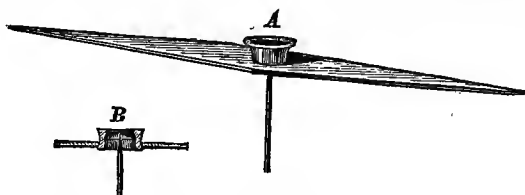


FIG. 122.

the flame, close one end, and cut off close to the closed part; the piece forms an excellent cap. Heat the glass cap until sealing-wax melts upon it, and press the magnetised needle upon it; secure



FIG. 123.

the cap with more wax; the point of a darning-needle, of which the eye end is fixed in a piece of wood or cork, serves as the pivot. If necessary grind one end in order to make the balance perfect.

The poles of a magnet.—The iron filings collect chiefly near the ends of the lodestone. The two points that possess the greatest power of attracting iron filings are called poles.

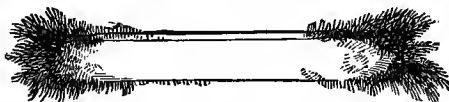


FIG. 124.

Dip the bar magnet and the horse-shoe magnet into the filings; the small particles arrange themselves chiefly near the ends. A similar result is obtained by using the small artificial magnets.

Rub a knitting-needle several times from end to end with one end of the bar magnet (see fig. 136), always beginning at the same end. The needle will be magnetised; dip it into the filings and observe a like result to the above.

The iron filings collect equally at both ends, and we infer that the poles have equal powers for attracting soft iron.

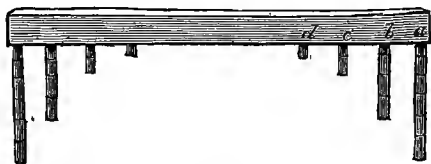


FIG. 125.

By attaching small cylinders of soft iron to the bar and to each other, we can roughly measure the strength of the magnet at various points (fig. 125).

The magnetic force is greatest at the poles (near the ends), it decreases towards the centre of the bar, while at the centre there is no magnetic force.

The names of the poles.—Suspend your magnets so that they can move in a horizontal plane. One particular end of each magnet always points towards the north. If we displace the magnet, it again sets north and south after a few movements.

Mark the end that points north in each, and call it the North-seeking end, and the respective pole the North-seeking pole; the other end is called the South-seeking pole, and its respective pole the South-seeking pole. The N-seeking end is generally stamped N, or a line is drawn across the bar. The

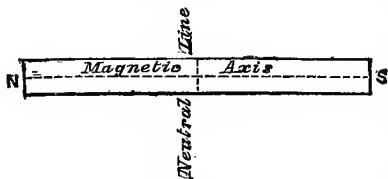


FIG. 126.

line joining the N-seeking pole to the S-seeking pole is called the magnetic axis.

Replace the magnets by pieces of unmagnetised steel, of soft

iron, rods of wood or glass, and convince yourself that the power of setting north and south is confined to magnets.

The differences between the poles.—Magnetise a knitting-needle as on page 142 ; mark its N-seeking end ; select another needle that is not magnetised ; and suspend all these in any convenient way. Bring the N-seeking pole of the magnetised needle near

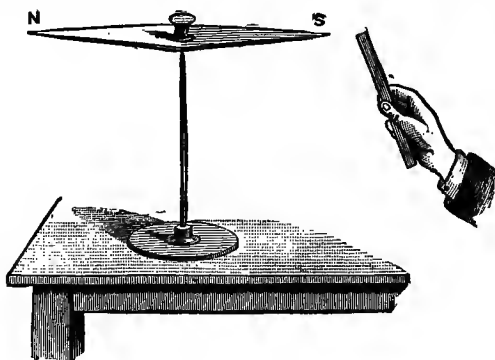


FIG. 127.

each end of the unmagnetised needle ; it attracts either end ; a similar result is obtained with the S-seeking pole. Repeat the experiment, using the bar magnets. Substitute for the unmagnetised steel a piece of soft iron (a long nail answers as well) ; similar results are obtained (fig. 127).

The attraction between the magnet and the soft iron is mutual ; if the soft iron be held in the hand it attracts either pole of a suspended magnet.

Hold one of the magnets in the hand by the S-seeking pole, say, and place the N-seeking pole in turn near the poles of the suspended magnet (fig. 128).

The N-seeking pole attracts the S-seeking pole, but repels the N-seeking pole.

A similar result is obtained with all the magnets. We have thus three tests for a magnet.

- (1) Its power of attracting soft iron filings.
- (2) Its power of setting north and south when free to move in a horizontal plane.
- (3) Its behaviour with a magnet whose poles are known.

The *repulsion* between poles of the same name is noteworthy. The N-seeking pole of a magnet repels the N-seeking pole

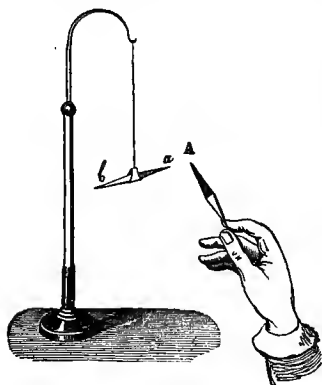


FIG. 128.

of any other magnet, while it attracts the S-seeking pole ; and the S-seeking pole of a magnet repels the S-seeking pole of any other magnet, while it attracts the N-seeking pole. This is sometimes expressed by saying that unlike poles attract and like poles repel. The action of two magnets upon each other, is not confined to the action of the nearest poles upon each other, although these poles have the greatest effect and

mainly determine the movements of the magnets ; the N-seeking pole of the first magnet will attract the S-seeking pole and repel the N-seeking pole of the second ; the S-seeking pole of the first will attract the N-seeking pole and repel the S-seeking pole of the second.

EXAMPLES. I.

1. What are the two general forms of magnets ? What are the advantages and disadvantages of each ?

2. In what parts of a magnet is the power of attracting particles of iron the strongest ? How would you show this by experiment ?

3. How would you show by experiment, that not only does a magnet attract a piece of iron or steel, but that the piece of iron or steel also attracts the magnet ?

4. You are doubtful whether a steel rod is neutral or is slightly magnetised ; how could you find out by trying its action upon a compass-needle ?

5. Two small steel magnets (for example, magnetised sewing needles) are fastened to bits of cork so as to float horizontally on a basin of water. Say exactly what will happen if the needles are left to themselves at a distance of a few inches apart on the surface of the water.

Magnetic Induction.—The permanent magnets are made

of hard steel ; we have already made small permanent magnets from steel knitting-needles.

Rub a soft iron nail from end to end with one end of a magnet, that is, try to magnetise it. Dip the nail into iron filings, suspend it, see if it repels either pole of a suspended magnet. You will find that either it remains unmagnetised, or the magnetism of the nail is of the feeblest description.

Dip one end of the soft iron nail into iron filings, it does not attract them. Bring one pole of a permanent magnet *near* the

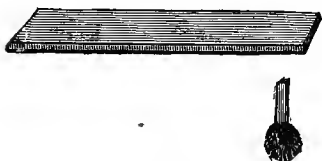


FIG. 129.



FIG. 130.

other end ; the filings are attracted (fig. 129), and the soft iron that we were unable to magnetise by rubbing, seems to be instantaneously magnetised. If the iron touch the magnet the effect is increased. Remove slowly the bar magnet ; the filings gradually drop off (fig. 130).

Substitute a hard piece of steel for the soft iron. The steel only shows the feeblest sign of magnetism, if any ; on removing the bar magnet the steel retains any slight power of attracting iron filings it may have acquired. Substitute rods of glass and of wood for the soft iron ; in no case do they show any tendency to attract the iron filings.

Soft iron, in the neighbourhood of a permanent magnet, becomes temporarily a magnet, it is said to be magnetised by *induction*. The magnetisation disappears as soon as the permanent magnet is removed.

Steel is in a very slight degree magnetised by induction, but the slight amount of magnetism induced, remains when the bar magnet is removed.

The poles of a temporary magnet.—Rest a bar of soft iron upon a support ; place a bar magnet *SN*, in the same straight line (fig. 131), its *N*-seeking pole nearest to the iron. Bring iron filings near the soft iron and show that it attracts them ; notice that the

filings congregate on the ends, just as if the iron were a magnet ; remove the bar magnet, the filings drop off. Replace them in position and bring a pole of a suspended magnetic needle *sn*

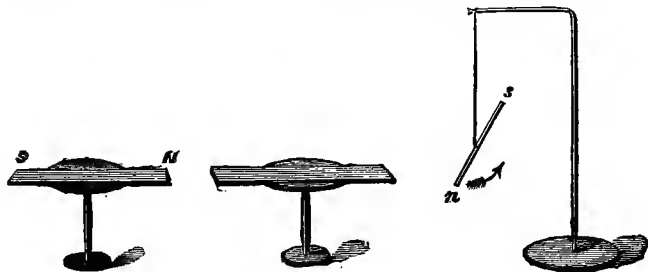


FIG 131

near the end of the soft iron that is farthest from the magnet. The N-seeking end is repelled and the S-seeking end is attracted. Reverse the positions of the poles of the permanent magnet ; at once the poles of the temporary magnet are reversed.

We therefore call the end of the soft iron nearest to the needle, a N-seeking end. Similarly by bringing the needle near the other end, we can show that it is a S-seeking end.

A permanent magnet induces magnetism in soft iron placed near it ; the end farthest removed from the magnet acts as if it were a pole similar to the nearest pole of the magnet.

It might be argued that the action upon the magnetic needle is merely the action of the permanent magnet itself. If in fig. 131 the soft iron bar be taken away, and the needle be removed so far from the magnet that it is not affected by it, then if a long soft iron bar be placed between the needle and the magnet, the needle is at once affected by the induced magnetism of the iron bar.

Substitute a piece of hard steel for the soft iron bar. No appreciable effect can be observed, as to the magnetisation of the steel bar ; if it remain for *some time* near a powerful magnet, it does become slightly magnetised by induction, and it retains its magnetism when the permanent magnet is removed.

Stand the horse-shoe magnet on its bend in a vertical plane. Suspend a soft iron nail over it horizontally by means of a silk fibre.

The nail sets parallel to the magnetic axis of the magnet. Bring a bar magnet near each end of the nail in turn (fig. 132).

The end of the nail over the N-seeking pole is repelled by the S-seeking pole of the bar magnet, and that end is therefore a S-seeking pole ; the end over the S-seeking pole of the horse-shoe magnet can similarly be shown to be a N-seeking pole. Keep the nail in the same position and turn

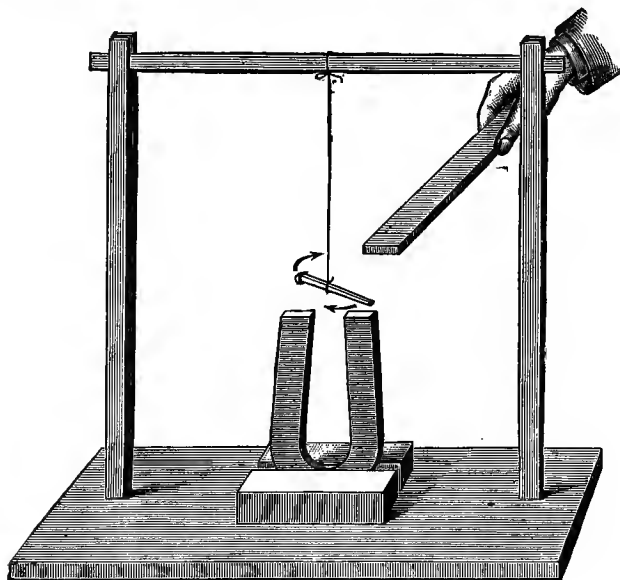


FIG. 132.

the horse-shoe magnet round, so that the positions of its poles are reversed. At once the poles of the soft iron nail are reversed.

Repeat the experiment, substituting a piece of hard steel for the soft iron nail. The magnetism, if any, is of the feeblest description. But again, if the steel remain long enough to acquire any magnetism, it retains it when the permanent magnet is removed.

Soft iron is magnetised easily by induction, but temporarily ; steel with difficulty, but permanently.

Magnetic attraction or repulsion is preceded by induction. The magnetic substance becomes a temporary magnet, and the nearest poles of the temporary magnet and the permanent magnet being of opposite kinds, attraction ensues.

Select two straight thin iron wires, and attach them to either pole of a magnet, say the S-seeking pole. Instead of hanging vertically, the lower ends repel one another.

Each is a magnet by induction ; the lower ends are each a S-seeking pole, and repel each other.

A permanent magnet can induce magnetism in one bar of soft iron ; this in its turn can induce magnetism in a second soft



FIG. 133.

iron bar, and so on if the permanent magnet be strong enough. The position of the poles in the soft iron will be as in fig. 133, as can be shown by means of a magnetic needle. The results are more marked if the bars be actually in contact. The N-seeking end of the permanent magnet induces a S-seeking pole in the small bar attached to it, and a N-seeking pole in the other end. This first temporary magnet, assisted by the bar magnet, induces a S-seeking pole in the nearest end, and the N-seeking pole in the farthest end of the second bar, and so on.

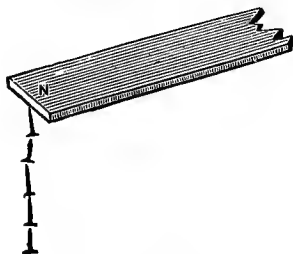


FIG. 134.

A magnetic chain.—If a number of pieces of iron be attached to a magnet a magnetic chain is formed. If the pieces be small rings of iron, the form of the chain is more apparent. A chain is readily formed with small iron nails (fig. 134). If attached to the N-seeking pole as in the figure, the point of each is a S-seeking pole, and the head a N-seeking pole.

If the particles be very fine, like iron filings (see fig. 129),

the same explanation holds; each particle by induction becomes a temporary magnet.

In any example of the magnetic chain, hold the piece attached to the magnet in the hand, and remove the magnet; all the parts lose their magnetism, and the chain falls to pieces.

Suppose we find that to either pole of a magnet—let us say the N-seeking pole—we can attach four pieces of soft iron and no more, what will happen if we bring a second magnet beneath the first, so that its S-seeking pole is beneath the N-seeking pole of the first? Evidently by induction each pole of

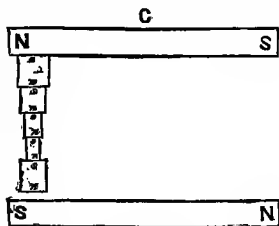


FIG. 135.

the pieces of soft iron will be strengthened; we shall find that we shall be able to attach one or more pieces to the chain (fig. 135).

The student can write out what will happen, and verify it by experiment, when the N-seeking pole of the second magnet is placed beneath the N-seeking pole of the first.

Induction across substances.—Repeat several of the above experiments, interposing sheets of paper, pieces of wood, sheets of glass, the hand, &c., between the magnet and the magnetic substance. Then interpose a sheet of soft iron.

Induction takes place readily across air, as in all the experiments; it also takes place across substances that are not magnetised by any of the methods we have employed. Magnetic force does not, however, act across a sheet of soft iron, and only partially across other magnetic substances.

EXAMPLES. II.

1. What substances are permanent and temporary magnets respectively made from?
2. A soft iron nail is held near the N-seeking pole of a bar magnet. What reasons can you give for calling the nail a temporary magnet?
3. Two long iron wires hang from the same pole of a magnet. Will they hang parallel to each other? Give a sketch of the two wires and give reasons for your answers.
4. Six unmagnetised sewing-needles are stuck vertically into small pieces of cork floating in a basin of water. What takes place when the

eyes are out of the water : (a) the N-seeking pole, and (b) the S-seeking pole of a bar magnet is held over them ?

5. In the last question, what will take place if the needles be magnetised so that the eye is a N-seeking pole ?

6. How would you separate a mixture of iron filings and sawdust by means of a magnet ?

7. What is the magnetic condition of a bar of soft iron held horizontally above, and parallel to, a permanent magnet of the same size, resting horizontally on a table ?

8. You have two similar rods, one of steel and the other of soft iron ; you have also a bar magnet and some small iron nails. Describe exactly some experiment which would enable you to distinguish the steel rod from the iron rod ?

9. A bar magnet is laid on a table with its north end projecting over the edge. A soft iron ball clings to the under side of the projecting end. State and explain what happens when the south pole of a second magnet is brought above and near to the north pole of the first ?

10. Two similar rods of very soft iron have each of them a long thread fastened to one end, by which they hang vertically side by side. On bringing near the iron rods from below, one pole of a strong bar magnet, the rods separate from each other. Explain this.

11. A magnet is placed near a compass-needle, so as to pull the needle a little way round. If a large sheet of soft iron be put between the magnet and the needle, what happens ? and why ?

12. If a compass needle be deflected when a steel bar is brought near it, how can you find out whether the deflection is due to magnetism already possessed by the bar, or to the bar becoming magnetised by the compass-needle at the time of the experiment ?

Methods of making magnets.—1. *Magnetisation by single touch.*—The bar of steel to be magnetised is rubbed with one

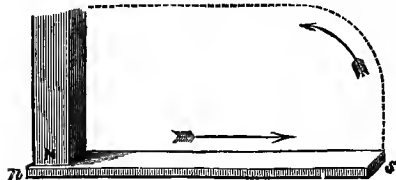


FIG. 136.

pole of a permanent magnet. Beginning at one end, the magnet is rubbed along the length of the bar ; it is then raised, carried to the first end, and the operation repeated several

times. The bar is then turned over, and the other side similarly treated (fig. 136).

Magnetise by single touch three or four needles, rubbing with the

N-seeking pole, beginning in each case at the eye and ending at the point. Test and mark the poles of the magnetic needles; in each case the eye will be a N-seeking pole and the point a S-seeking pole.

The end last touched is always a pole of opposite name to the touching pole.

2. *Magnetisation by divided touch.*—The steel rod is placed horizontally; two bar magnets are placed upon it at its centre, their opposite poles being together. They are then drawn

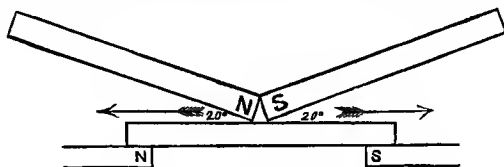


FIG. 137.

apart simultaneously to the ends of the bar; the magnets are lifted, replaced on the centre, and the operation repeated. The bar is turned over and rubbed similarly on the other side. It is an improvement to rest the rod upon the poles of permanent magnets, the poles being of the same names as those of the rubbing magnets above them. The poles of the magnetised bar are of opposite name to the pole that last touches them.

3. *Magnetisation by the action of the earth.*—This will be explained on p. 152.

4. *Magnetisation by an electric current.*¹

Armatures and keepers.—Magnets lose their power of attracting iron and steel unless provided with armatures. These are pieces of soft iron placed in contact with the poles, each connecting a north and south pole. The

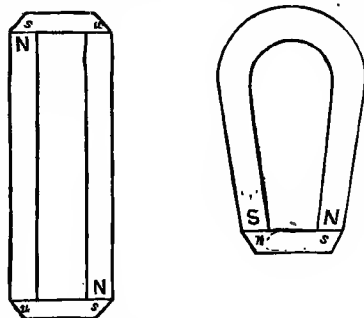


FIG. 138.

armatures or keepers become magnets by induction, and tend to preserve the magnetic condition of the magnets. In the

¹ See Voltaic Electricity.

horse-shoe magnet (fig. 138) the pole marked *s* induces magnetisation in the keeper; it becomes a temporary magnet with its poles *n s*. The pole marked *N* likewise acts by induction, inducing poles *n s*. These effects of the two poles are added to each other, but the result is more than double the effect of one pole, because the pole *s* induced by *s* acts by induction upon *N* and strengthens it; it in its turn reacts upon *s* and *n*; the induced pole *n* similarly acts upon *s*.

EXAMPLES. III.

1. How would you magnetise a sewing needle, so that the point shall be a N-seeking end?

2. A pen-nib remains attached for some time to a horse-shoe magnet, so that it touches each pole, the point being in contact with the north pole. On removing the pen it is found to be slightly magnetised. (How would this be proved?) Which pole will be situated near the point? Give reasons.

3. A bar magnet is placed on a table; $\frac{1}{4}$ " from the N-seeking end a piece of soft iron is placed; $\frac{1}{4}$ " from its S-seeking end an equal similar piece of steel is placed; all three are in the same straight line. Iron filings are brought near the ends of the iron and steel that are farthest from the magnets. What will happen in each case, and why? A delicate compass-needle is brought near the same ends. What will take place when the N-seeking pole is brought near each?

4. A piece of soft iron, placed in contact with both poles of a horse-shoe magnet at the same time, is held on with more than twice the force with which it would be held if it were in contact with only one pole of the same magnet. Why is this?

5. Why is less force required to pull a small iron rod away from the poles of a powerful horse-shoe magnet, than would be required to pull a thick bar of iron away from the same magnet?

6. You have three equal bar magnets without keepers. How would you arrange them, so that, when not in use, they might preserve their magnetism? Give a sketch.

7. A bar magnet is held vertically and two equal straight pieces of wire (soft iron) hang downwards from its lower end. The lower end of each of these wires can by itself hold up a small scrap of iron; but if the lower ends of both wires touch the same scrap of iron at the same time, they do not hold it up; what is the reason of this?

8. You have a bar magnet and a steel knitting-needle, one end of which has been marked (say by having been dipped in ink). Say exactly what you would do in order to magnetise the knitting-needle so as to make the marked end a N-seeking pole, and the other a S-seeking pole, and how would you find out whether you have succeeded?

CHAPTER II

TERRESTRIAL MAGNETISM

Magnetic Dip.—Place a small magnetic needle on a stand ns (fig. 139), upon a bar magnet NS , so that its pivot is over the centre of the bar magnet. The needle sets parallel to the bar magnet, its N-seeking pole being towards the S-seeking pole of the bar magnet, and its plane horizontal; move the stand towards one end of the bar magnet, the needle dips its point towards the pole at that end.

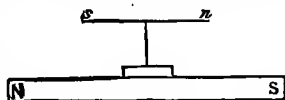


FIG. 139.

A magnetic needle suspended by a single silk fibre can dip more freely and is more suitable for this experiment (fig. 140).

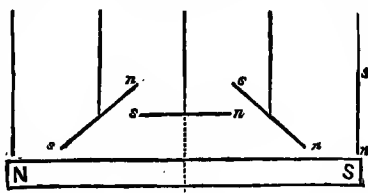


FIG. 140.

A strong magnet is able to coerce a weaker magnet into pointing in the same direction; the strong magnet also causes the weaker magnet to dip, the magnetic axis of the weaker pointing to the nearer pole of the stronger magnet; the dip increases as the small magnet approaches a pole; exactly over a pole, the needle hangs vertically.

This suggests that the reason why magnets set north and south is, that the earth is acting as if it were a magnet. Does a magnet, however, dip when under the influence of the earth's magnetism? The magnetic needles we have hitherto used are horizontal.

Balance an *unmagnetised* knitting-needle upon a knife-edge, and

find its centre of suspension. Attach a silk fibre to the centre with a drop of shellac varnish. Suspend the needle by the fibre, and, by filing one end if necessary, arrange so that it hangs horizontally. Now magnetise the needle.

It sets north and south, but its N-seeking end also dips. To use the needle as an ordinary magnet, we must file off part of the N-seeking end.

The angle between the direction of the dipping needle and

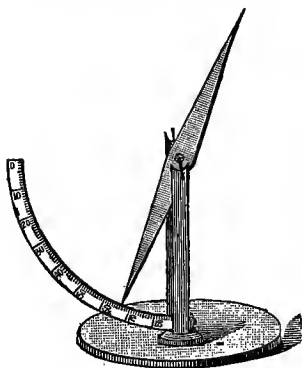


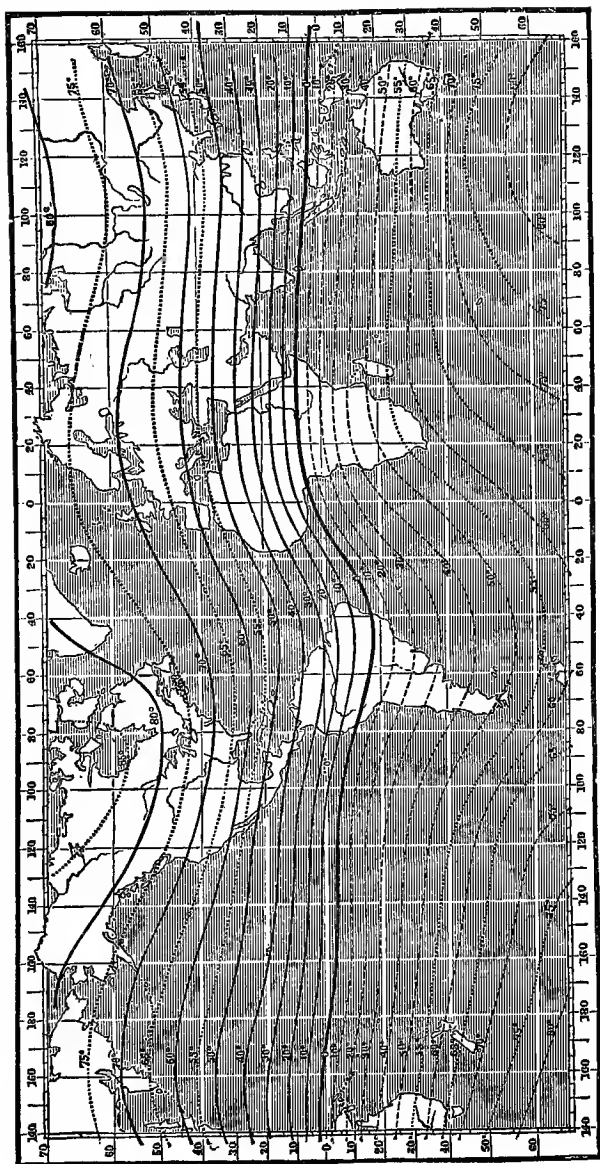
FIG. 141.

a horizontal line in the same plane is called the *angle of dip* (fig. 147). A simple dipping needle is illustrated in fig. 141. The axis of the needle by which it is suspended, passes exactly through the centre of suspension and is inserted before the needle is magnetised. After magnetisation the needle when placed in the magnetic meridian, indicates the angle of dip on the graduated arc. On turning the stand, the inclination increases; when the

plane of the needle is at right angles to the magnetic meridian the needle hangs vertically.

The angle of dip in England is $67\frac{1}{2}^{\circ}$. It varies in different parts of the globe, increasing as we approach the magnetic poles.

Isoclinic Lines.—A curve connecting all places that have the same dip is called an isoclinic line. The line joining all places where there is no dip is called the magnetic equator; it is analogous to the geographical equator, is near it but does not coincide with it. The isoclinic lines are analogous to lines of latitude; but the isoclinic lines are not parallel to each other, and the curves are not regular. (See map, p. 147.) At the magnetic poles the needle would stand vertically. The north magnetic pole is $96^{\circ} 43'$ west longitude, and 70° north latitude; there is a similar south magnetic pole. The poles and the isoclinic lines are not fixed, their position varies from time to time. The variation in the angle of inclination or the angle of



Map showing lines of equal magnetic dip.

dip as a dipping needle is carried round the earth is illustrated in the diagram fig. 142.

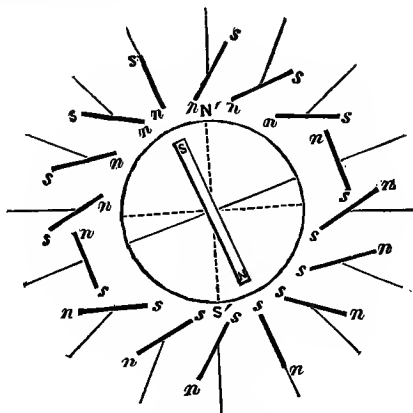


FIG. 142.

Declination.—The direction of a magnetic needle in England is to the west of the true northerly direction, as determined by the polar star. The angle between the line pointing to the true north, and the direction of the magnetic needle, is called the *angle of declination*. The declination is constantly varying. In 1885 at London it was $18\frac{1}{2}^{\circ}$ W.; in 1878 it was 17° W.; in 1700, $8^{\circ} 10'$ W. The curve connecting those places, in which the angle of declination is the same, is called an *isogonic line*. These curves are irregular. (See map, p. 149.)

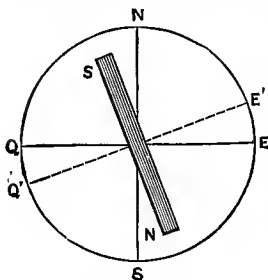
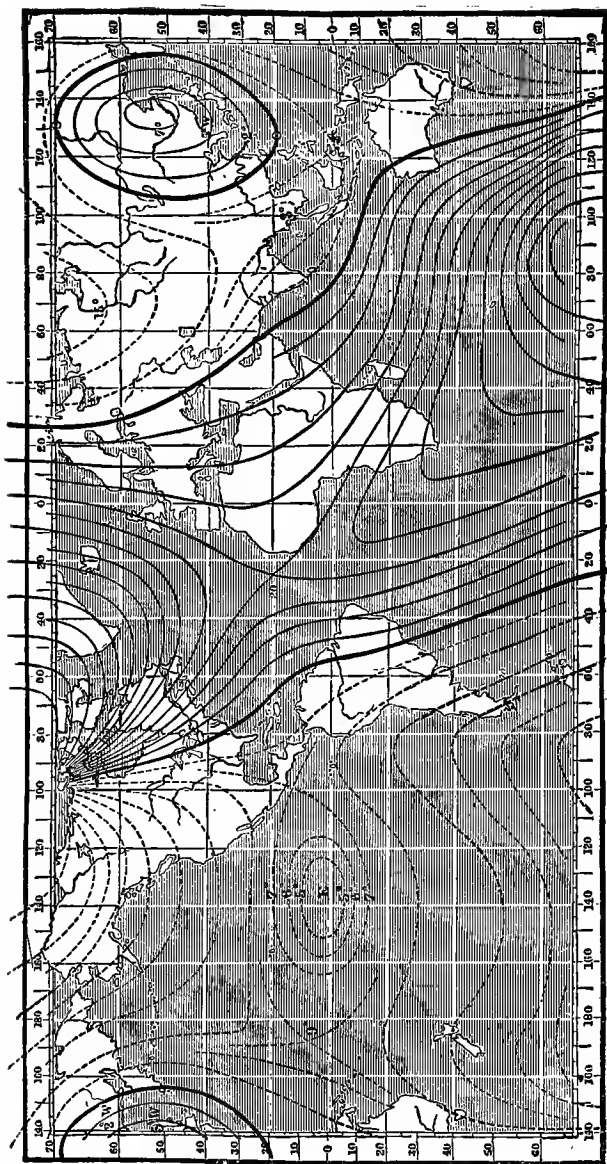


FIG. 143.

The earth as a magnet.—Many of the phenomena in reference to the dipping, and the inclination of magnetic needles, can be explained by imagining that a short thick magnet pierces the centre of the earth. This magnet if produced would cut the crust of the earth at the points called the north and south magnetic poles.

The direction of the axis of the assumed short magnet, that we imagine to be the cause of the earth's magnetism, does not, then,



Map showing lines of equal declination.

coincide with the axis of the earth, but makes an angle with it ; we must call the end near the north pole a S-seeking pole, seeing that it attracts the N-seeking pole of a needle. In fig. 143 $E Q$ represents the geographical equator, and $E' Q'$ roughly the position of the magnetic equator.

The Mariner's Compass.—This compass in its simplest form is a small magnetic needle on a pivot, set in the centre of

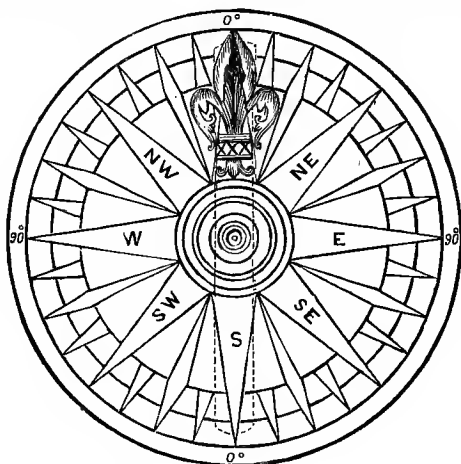


FIG. 144.

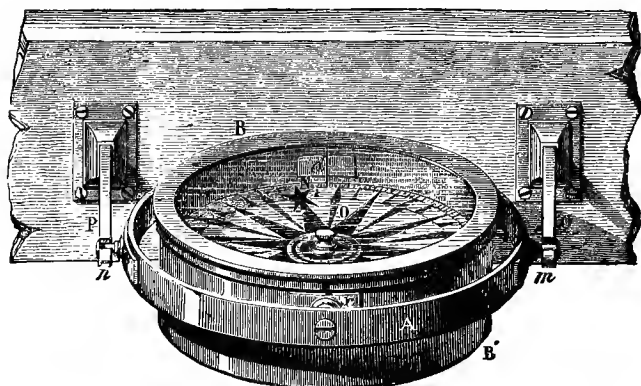


FIG. 145.

a card, divided as in fig. 144 ; the whole is encased in a box. The box is turned until the line *NS* makes an angle of $18\frac{1}{2}^{\circ}$ (or whatever the angle of declination may be) to the east with the direction of the magnetic needle compass ; the points on the rose are now towards the true geographical directions. In the compass as used in ships (fig. 145) the needle is not visible, it is

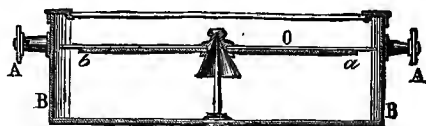


FIG. 146.

securely fastened to the underside of the card (fig. 146), so that both needle and card move together on the pivot. The case is suspended on gimbals, in order that the pivot may always remain vertical as the ship rolls. A direction from the centre of the card to *d* (fig. 145) is the direction of the keel of the ship. The whole is placed in the binnacle ; the sailor told to steer N.W., say, turns the ship until the branch of the star marked N.W. points to *d*.

EXAMPLES. IV.

1. What do you mean by the term magnetic dip? Why does an ordinary compass not dip?
2. If you were provided with a dipping needle how would you find the north magnetic pole? How would you find the south magnetic pole with a declination needle?
3. 'The earth is a magnet.' What does this mean? Is there a magnet passing through the centre of the earth?
4. Describe the mariner's compass. Is it a dipping needle or a declination needle? Will the compass be more likely to act accurately in a wooden ship or in an iron ship? Why?
5. How does the position of a 'dipping needle' change when it is taken from London (1) towards the north pole, and (2) towards the equator?
6. What is meant by saying that the magnetic dip at London is $67^{\circ} 30'$?
7. State in general terms at which places on the earth's surface the magnetic dip is least?
8. If you wish to support a uniform bar magnet horizontally on a pivot,

how is it that the pivot must be placed nearer to one end than to the other. To which end must it be nearer in this country?

9. If a compass were carried round the equator, would it point in the same direction at all places. If not, state as nearly as you can what changes would be observed in its behaviour during the journey.

Magnetisation by means of the earth's magnetism.—Soft iron becomes a magnet by induction when in the neighbourhood of a strong magnet; this magnetisation is more readily imparted if the iron be beaten. The earth can be used as the inducing magnet.

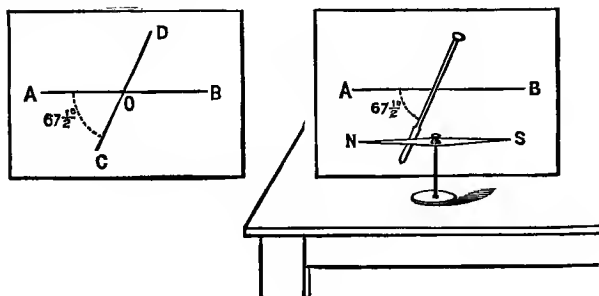


FIG. 147.

Find the magnetic meridian—that is, the line pointing to the magnetic pole. On a sheet of cardboard draw a line AB parallel to the edge, and another line DC making an angle of $67\frac{1}{2}^\circ$ with AB. Stand the cardboard vertically so that AB points to the magnetic north; then DC is pointing to the S-seeking pole of the assumed earth magnet (fig. 147). Remove the needle. Place any bar of soft iron (prove first that it is not magnetised) such as a poker in the direction DC. While in that position strike it several times on the head with a hammer, then test it with the needle; the end pointing downwards will be found to be a N-seeking pole, the other end a S-seeking pole.

It is difficult to adjust compasses in an iron ship on account of the magnetism induced in the plates. The magnetisation of the plates depends upon the position in which the ship was built, the amount being aided by the hammering to which the plates have been subjected.

If the poker be made of good wrought iron, the blow is

not necessary, and the experiment shows how rapidly soft iron can be magnetised and demagnetised by induction.

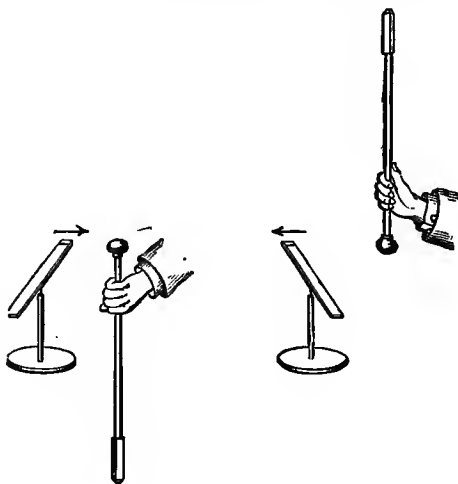


FIG. 148.

Hold a poker point downwards, with the head near the N-seeking end of a needle (better still point it in the direction DC as in fig. 147). The head attracts the N-seeking end, proving it is a S-seeking end. Without changing the position of the head invert the poker; at once the head repels the magnet; it has become a N-seeking end (fig. 148).

The magnetic field.—The earth (acting as a huge magnet), strong magnets, and to a less degree all magnets, exert a power over the space surrounding them; smaller magnets in this place set or tend to set in certain definite directions, small pieces of soft iron become magnets by induction, and act similarly. The space through which a magnet exerts its power is called a magnetic field. We frequently study it in one plane only, but must not forget that the space would be a solid. In the magnetic field pieces of soft iron become magnets by induction, and are under the influence of the force that sets them, or tends to set them, in certain definite directions. These directions are called lines of force. We find the direction of

these lines of force by taking a very small magnet, placing it in any part of the field, and marking its direction ; it is then moved so that one end takes the place lately occupied by the other end, and another portion of the curve is obtained.

Magnetic curves.—The magnetic field is best studied by means of iron filings. Fine filings are sifted through fine muslin

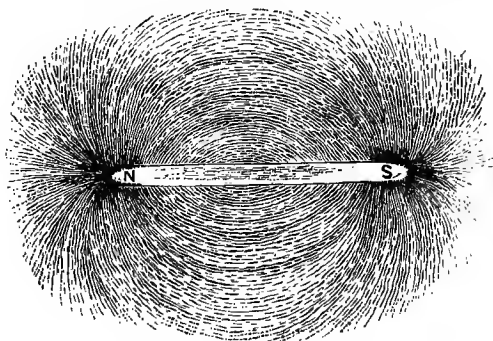


FIG. 149.

upon a sheet of cardboard or glass ; underneath is placed a single magnet or a combination of magnets. When the glass is tapped, the filings arrange themselves in curves. The direction

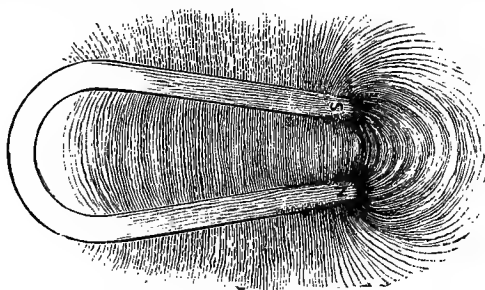


FIG. 150.

of the curves at any point is the direction any small needle would rest in under the influence of the respective poles. The curves called by Faraday, **LINES OF FORCE**, begin at a pole, and end in a pole of opposite name. The filings congregate the thickest

where the field is strongest. The action of a magnet on magnetic bodies, we learn, is not due to one pole, but to the action of both poles. The magnetic fields due to (1) a bar

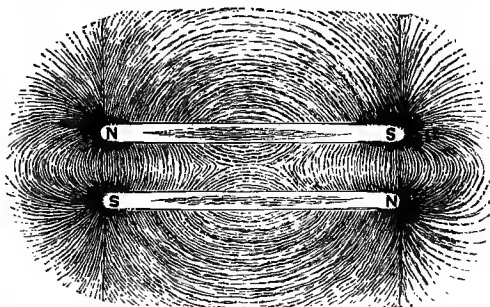


FIG. 151.

magnet (fig. 149), (2) a horse-shoe magnet (fig. 150), and (3) two magnets with poles of opposite names near each other (fig. 151) are illustrated.

The form of the curves of a magnetic field can be preserved, by placing over the filings a sheet of paper, that has been brushed over with a solution of nut-galls; each piece of iron acts on the solution and prints a blue mark. When the paper is dry the filings can be shaken off.

By examining the lines at some distance from two poles of opposite name (fig. 151) and considering only *a small portion* of the magnetic field, we see that the lines of force are practically parallel. This is the case in the magnetic field at any part of the earth's surface due to the action of the earth as a magnet. The poles of a compass needle are acted upon by two parallel forces, that tend to twist the needle on the pivot, but have no tendency to draw the needle towards either magnetic pole.

Place a magnetic needle on a cork floating on still water (fig. 121). The needle soon sets north and south, but displays no tendency to move towards the north as a whole.

Breaking a magnet.—Straighten a piece of watch-spring; heat it and throw it into water; magnetise it and mark its poles. Break it into halves. Test each half; each will be found to possess

a N-seeking and a S-seeking pole (fig. 152). Break each half again; each piece possesses poles. This is the case no matter how

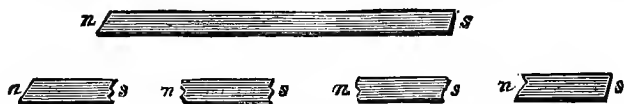


FIG. 152

small the pieces may be. If the pieces be placed together again so as to form one magnet, the intermediate poles disappear, only those at the ends being apparent.

We infer that if a magnet could be broken into the smallest possible pieces, then each of these small pieces, called molecules, *c* (fig. 153), would be a magnet with a N-seeking

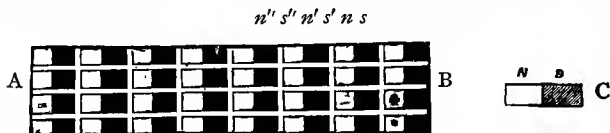


FIG. 153.

and a S-seeking pole—a division beyond our powers, and the pieces would be so small that no microscope could detect them. It is also argued, that the magnetism of a magnet is due to the magnetism of its molecules; that in a magnet all the poles of one name are turned in one direction, so that the intermediate poles neutralise each other, and only those towards the end are effective. The shaded space and light space *N S* (*c*) together represent one of these molecules or small bodies that cannot be further divided, that is, it is impossible to separate the parts we distinguish by shade. If the magnet *A B* be broken, the end *A* being a N-seeking pole, the other end of the broken magnet must be a S-seeking pole.

In the case of an unmagnetised bar the molecules are arranged irregularly, there being no symmetry in the arrangement. When stroked with a magnet they tend to turn so as to form a series like fig. 153. The molecules easily turn in soft iron, a fact we also infer from the easy way it can be bent so as to assume any shape; therefore it is easily magnetised

by induction ; but the strong magnet being removed, the molecules drift back into their irregular position, and the bar loses its magnetic power.

In hard steel the molecules turn with difficulty ; if we bend it, it springs back to its former position, and breaks rather than assume a new permanent position. Hence, to magnetise it, it must be rubbed strongly several times. On stroking a steel bar a few times, part of the molecules turn, and the bar is feebly magnetised ; as we continue stroking, more of the molecules turn and the magnetisation increases. The bar is fully magnetised, or is said to be saturated, when the whole of the molecules have been turned. Once magnetised, it is as difficult to change the molecules from their second position as it was to change them from their first position ; it remains a magnet. When a body is heated, the molecules separate and can move more easily. If a piece of steel be made red-hot, and then be allowed to cool, resting in the position pointing towards the magnetic pole, the magnetism of the earth acts upon the molecules, and some of them turn, the steel becomes magnetised by induction, and on cooling in this position remains a magnet.

The student can apply his theory to the various experiments in re-reading the book. It will assist him to classify the experiments, when he imagines the rotation of these molecules, always remembering that they are so small that the motion can never be observed, and that it is a theory that may be modified, or even rejected, if it fail to explain, or if it oppose any actual fact observed in experiment.

The following experiment supports this theory of magnetism
A test-tube is nearly filled with iron filings. If either end be presented to a needle, attraction takes place. No poles are observable in the test-tube of filings. Now draw a powerful magnet *several times* from end to end, as in mag-

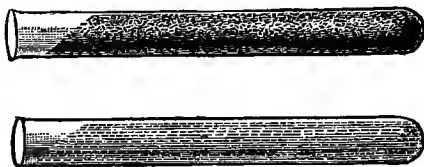


FIG. 154.

netisation by single touch. The particles set themselves in the direction of their length. The iron filings will not be all of soft iron ; they retain part of the magnetisation, and, on bringing a magnetised needle near, it will be seen that the tube of filings acts like a magnet. Shake the filings up ; no trace of magnetisation can be detected, they have assumed again their unsymmetrical positions.

EXAMPLES. V.

1. Two precisely similar magnets are placed vertically with their lower ends on a horizontal table. Iron filings are scattered over a plate of glass which rests on their upper ends, one of which is a north pole, and the other a south pole. Give a diagram showing the forms of the lines of force mapped out by the filings.

2. A strong bar magnet is set upright, and a sheet of cardboard rests horizontally on the top of it. Describe and show by a sketch the way in which iron filings sprinkled on the cardboard arrange themselves.

3. The ends of a bar magnet have the property of attracting iron, but between them there is a part where this property is entirely absent. If the magnet be broken across at the neutral part, what are the properties of the two pieces ?

4. If you were required to make a model to illustrate the magnetic properties of the earth by putting a bar magnet inside a ball of clay, show by a sketch how you would place the magnets, and explain how the magnetic properties of the model would answer those of the earth.

5. If a long bar of very soft iron be held upright, how is it that its upper end repels the S-seeking end of a compass needle and that its lower end repels the N-seeking end of a compass needle.

6. Two equal bars of steel, after having been magnetised equally, are kept for some years in a vertical position, one (*a*) with its S-seeking pole upwards, the other (*b*) with its N-seeking pole upwards. The bars are so far apart that they do not act on each other ; which of the two would keep its magnetism best ; and why ?

7. The beam of a balance is made of soft iron. When it is placed at right angles to the magnetic meridian, two equal weights placed in the opposite pans just balance. Will the weights still appear to be equal when the balance is turned so that the beam swings in the magnetic meridian ? Give reasons for your answer.

8. A small magnet is placed on a flat cork which floats in a basin of water, and is fastened to the cork by a little sealing-wax. Describe and explain the behaviour of the magnet, (1) when under the influence of the earth's magnetism alone, (2) when an artificial steel magnet is brought near to it.

FRICTIONAL ELECTRICITY

CHAPTER I

ATTRACTION AND REPULSION

Introduction.—Thales, a Greek philosopher who lived 600 B.C., knew that when amber was rubbed with silk, it attracted light bodies. Dr. Gilbert, in the reign of Elizabeth, showed that other substances, such as sulphur, wax, and glass, when rubbed, were also able to attract light bodies. The Greek name for amber is *electron*; from this is derived electricity, the word used to describe the phenomena dealt with in the following pages.

Electrical attraction.—Rub a stick of resin or sealing-wax with flannel or catskin, and hold it near particles of paper, bran, feathers, or gold-leaf. The particles are attracted, they leap to the rubbed substance; some are then repelled, while others remain attached (fig. 155). Sticks of shellac and sulphur, and rods of ebonite may be substituted for the sealing-wax. A glass tube closed at one end, thoroughly cleaned and warmed, rubbed with silk

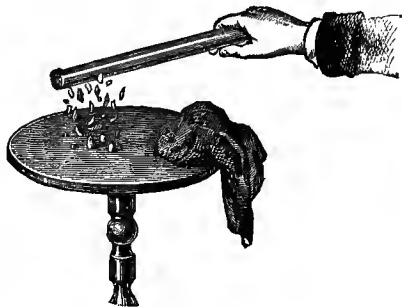


FIG. 155.

possesses a similar property of attracting light bodies, the best result being obtained if amalgam be spread upon the silk.

Cylinders made of drawing-paper (preferably of gilt paper), or dry egg-shells, can be conveniently used for the light bodies ; they roll after the rubbed bodies. The rubbed resinous bodies, or glass, will also attract tufts of cotton, or particles of dust floating in the air.

Rods of brass, iron, or of metals generally, if held in the hand and rubbed, do not possess the power of attracting light bodies.

The attraction is not confined to light bodies.

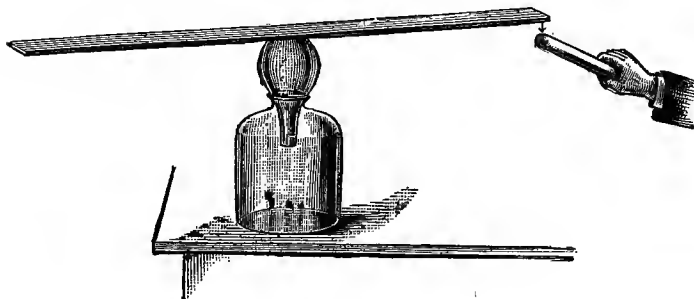


FIG. 156.

Balance a lath of wood upon an inverted flask, or upon an egg. The rubbed substances attract it (fig. 156).

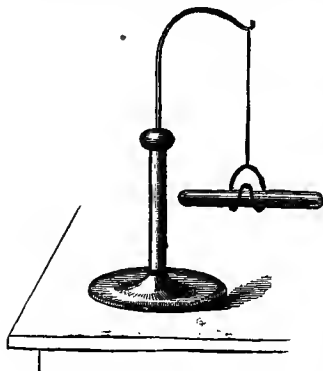


FIG. 157.

The attraction is mutual ; wood or other substances attract the rubbed bodies.

Rub the ebonite with flannel, or the glass with silk, and place either in a stirrup (fig. 157). Hold the lath, a piece of paper or the finger near ; the rubbed body will be attracted.

The glass rod moves very readily if it be balanced on a needle. The middle of the glass is softened in a Bunsen flame and a small indent is made with a hot wire (fig. 158). This is generally the most convenient method for

balancing the electrified bodies. The rods of wax, resin, &c., should be indented with a hot wire, and small glass caps (see p. 133) inserted.

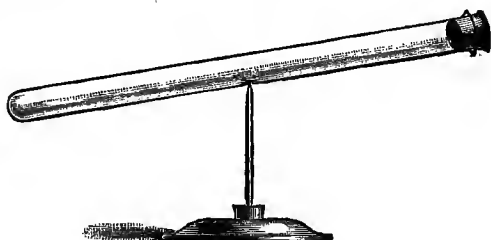


FIG. 158.

The above by no means exhaust our methods of showing that certain bodies after being rubbed, possess the property of attracting substances, and the student will be continually adding to his store of experiments.

Dry thoroughly a sheet of brown paper, make it as hot as possible, place it upon a dry board, and rub it with a hard clothes-brush; the paper clings to the board; on removing it, and placing it near a wall, we find it clings to the wall. Rub the paper again, fold it up, and present it to the balanced lath; again attraction takes place. Just after rubbing the paper, bring it near the face, a peculiar effect is experienced, the hairs on the skin are attracted, and a slight crackling is heard; if the experiment be performed in a dark room sparks can be seen. Treat similarly foreign post paper, rubbing it with india-rubber.

Slip two fingers into pieces of vulcanised india-rubber tubing, and draw a silk ribbon between them. The ribbon clings to the wall when placed near it and also attracts the balanced lath. A collodion film simply drawn between the dry fingers also attracts the suspended bodies.

A body that attracts substances after being rubbed, is said to be electrified, or electrically charged. The state or condition of the body is changed for the time being, so that it possesses new properties; but no material substance has been added to or taken away from it, as there is no change in the mass of the body. The term *electrification* is used to describe the state or condition of an electrified body.

Damp is an enemy to successful electrical experiments, and

failure is generally due to the fact that the apparatus is not perfectly dry. All materials should be kept in front of an open fire, or should be warmed before use. The experiments succeed best on a dry frosty day.

The balanced lath is at times scarcely delicate enough, a more sensitive piece of apparatus is shown in fig. 159. A piece

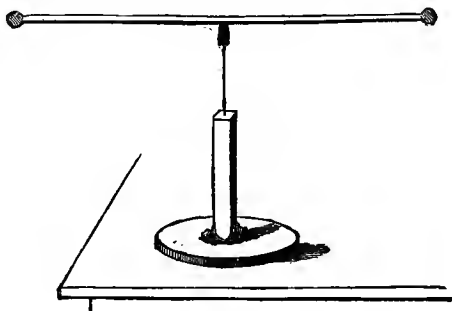


FIG. 159.

of gilt paper is attached to each end of a straw, the cap in the centre, is a small piece of straw fastened with sealing-wax; it rests upon the eye end of a needle. A very small amount of electrification produces attraction.

Pieces of pith or cork, shaped into balls and suspended by cotton thread from any convenient support, may also be used. Repeat the experiments with the resinous rods and the glass, using the balanced straw and pith balls.

On experimenting, with the most delicate pieces of apparatus, we fail to electrify pieces of brass or iron when held in the hand.

Electrical repulsion.—The student cannot have failed to observe, that not only were bodies attracted, but that when contact took place, they were frequently repelled.

Electrify the glass rod with amalgamed silk, place it in the stirrup or, better still, balance it as in fig. 158, at the same time let an assistant electrify the stick of vulcanite or sealing-wax with flannel. Hold the electrified sealing-wax near the glass; the glass is attracted.

There is nothing apparently new in the experiment, we

know that a non-electrified body will attract electrified glass or sealing-wax.

Again electrify the glass and suspend it, and similarly electrify a second rod of glass ; on presenting the second rod to the first, we observe that the balanced rod is repelled. Rub the rod of sealing-wax with flannel and suspend it ; electrify similarly a second rod of sealing-wax, and place it near the first.

The first rod is repelled by the second. The electrified sealing-wax is also repelled by a rod of sulphur rubbed with flannel, and by a rod of vulcanite rubbed with flannel.

Glass rubbed with amalgamed silk repels glass rubbed with amalgamed silk. Sealing-wax rubbed with flannel repels sulphur rubbed with flannel, or vulcanite rubbed with flannel.

Two kinds of electrification.—The electrification produced on glass rubbed with amalgamed silk, is called vitreous electrification, this name being given to all that form of electrification that *repels* glass rubbed with silk. The electrification produced on sealing-wax rubbed with flannel is called resinous electrification, and all electrification that *repels* sealing-wax rubbed with flannel, is called resinous electrification.

Rub a thin sheet of hot writing-paper, placed on a hot mahogany board, with a piece of india-rubber ; fold it up, and bring it near the suspended glass rod rubbed with amalgamed silk ; the rod is repelled.

The electrification of paper rubbed with india-rubber is vitreous.

Again rub the paper ; cut it into strips with a sharp knife as it lies on the board, leaving a band at one end ; roll the band together and lift the paper. The strips repel one another, being similarly electrified. Bring the excited glass rod near the strips ; they are repelled ; the resinous electrification of the sealing-wax attracts them.

Vitreous electrification is also called positive electrification, and resinous, negative electrification. The terms positive electricity, and negative electricity, are sometimes

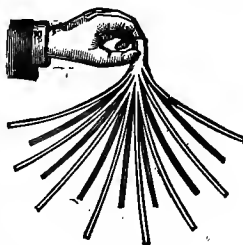


FIG. 160.

used ; but as we neither know anything about two distinct electricities, nor of electricity as a thing by itself, the phrases are misleading. The naming of the electrifications is purely a convention ; they might have been called A and B electrifications.

The balanced glass rod positively electrified, and the balanced stick of sealing-wax negatively electrified, can be used to test the kind of electrification a body may possess. A pith ball (preferably covered with gilt) suspended by a *dry silk thread* can be used for the same purpose. It is touched by a rubbed rod of vulcanite to charge it negatively, and by a rubbed glass rod to charge it positively, and the body whose state, as regards electrification, is to be tested, is brought near it. The test depends upon the repulsion.

EXAMPLES. I.

1. Explain the origin of the term Electricity.
2. You are provided with rods of glass, iron, vulcanite, and copper, and rub each in turn with rubbers of flannel and silk. Which of the rods will attract pieces of paper ?
3. Explain the meaning of electrification ; when are the terms resinous and vitreous applied ?
4. You have a rod given you, how would you proceed to electrify it, and how would you prove that it was electrified ? By what experiments would you discover whether the electrification was positive or negative ?
5. The pieces of paper attracted by an electrified rod of vulcanite are repelled after they touch the vulcanite. What can you suggest as the explanation ?
6. An electrified glass rod attracts a pith ball suspended either by a cotton thread or a silk thread ; after the ball touches the glass rod, it is repelled if suspended by silk, but is still attracted if suspended by cotton. Can you give any explanation of this with your present knowledge ?

The Gold-leaf Electroscope.—A bell-jar is fitted with a good india-rubber cork (fig. 161), through the centre of which, passes a glass tube ; the tube being filled with shellac, the shellac is melted, and a thick copper or brass wire pushed through. To the top of the wire a circular piece of brass or copper (a smooth penny) is soldered, the other end is flattened. The bell-jar fits into a circular groove in a board that should be covered with tinfoil ; or

three pieces of cork may be glued to the board, so that they press against the inside of the glass when it is placed over them, the friction is sufficient to keep the board in position. Two pieces of wood covered with tinfoil, or two metal rods, are fixed perpendicularly to the board. The leaves are placed midway between these. Thoroughly clean and dry the jar, cut two strips of gold-leaf, tip the flattened piece of rod with gum and attach the gold strips. Calcium chloride is placed in a small basin or crucible inside the jar, to absorb the moisture and keep the interior dry. The metal strips are purposely inserted; in simpler forms these are omitted (fig. 162), and a wide-mouthed jar or flask takes the place of the ordinary bell-jar.

The gold leaves are delicate and are easily injured. For rough experiments two gold-covered pith balls suspended by cotton threads are very convenient (fig. 163).

The use of the Electroscope.—Rub the glass rod and approach it to the disc; the leaves (or the pith balls) diverge. Try with rubbed rods of wax and vulcanite; again the leaves diverge; on removing the electrified body the leaves collapse. Unelectrified bodies have no effect upon the leaves.

The divergence of the leaves, without contact, indicates that an electrified body is near; the reason you will learn later.

Touch the disc with the electrified glass rod, draw it gently along the disc, the leaves diverge; on removing the rod, the leaves remain apart. Touch the disc of the electroscope with the finger; the leaves collapse; no sign of electrification is afterwards seen.

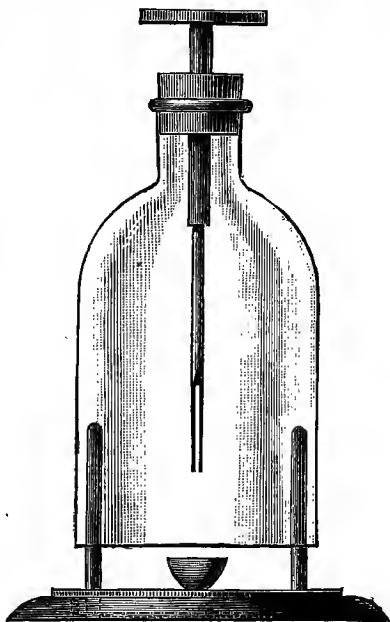


FIG. 161.

Positive electrification has been communicated to the disc and thence to the leaves, by touching the disc with the glass

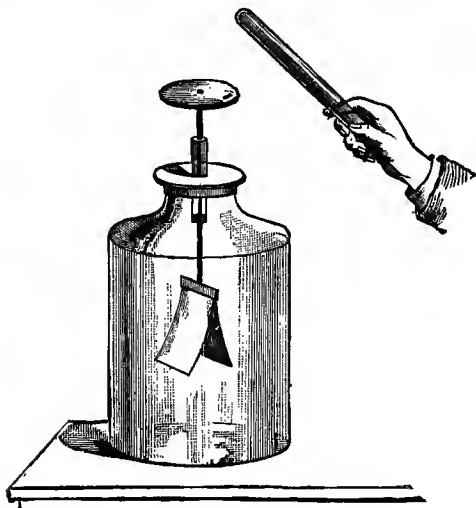


FIG. 162.

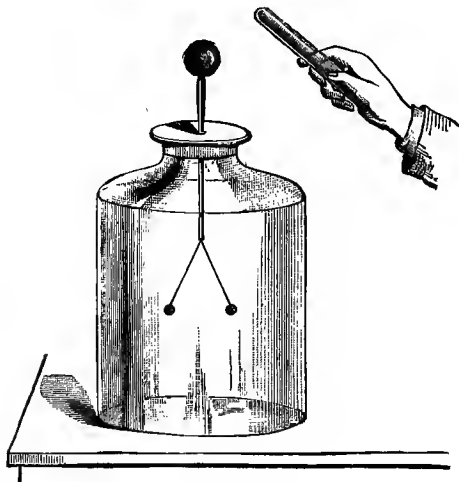


FIG. 163.

rod, the leaves being similarly electrified, repel each other ; the electroscope is said to be charged. On touching the charged electroscope with the hand the electrification disappears from it, the electroscope is discharged.

Repeat the experiment with rubbed sealing-wax, and, by touching, discharge the negative electrification.

Charge the electroscope with the rubbed glass rod, until the leaves are slightly apart ; again approach the electrified glass rod ; the divergence increases. When the rod touches the cap, the divergence increases further. Approach the rubbed rod of vulcanite ; the leaves previously charged positively, by contact with the electrified glass rod, partially collapse. Touch the disc with the vulcanite rod, and a further collapse takes place. The collapse may even be followed by a divergence.

Discharge the electroscope, and charge it negatively, by using a rubbed rod of vulcanite ; if any substance charged negatively be brought near the electroscope, a further divergence of the leaves will take place.

While the electroscope is charged positively or negatively, bring a non-electrified body near, a slight collapse follows.

We can determine the kind of electrification a body possesses, by bringing it near a charged electroscope, if we know the nature of the electrification first imparted to the electroscope ; it is upon the increased divergence that we must depend. The explanation of the action of the electroscope will follow in Chapter II.

Positive and negative electrification.—The electrification upon glass, is not always that known as vitreous or positive electrification.

Rub the dry glass tube with amalgamed silk, and draw it along the disc of the electroscope, until there is a divergence of the leaves. Now heat the rod as hot as you can bear to work with it, rub it with fur, and bring it near the disc ; the leaves begin to collapse. We infer, that either the glass is negatively electrified, or that it is not electrified at all. Discharge the electroscope, and touch the disc with sealing-wax rubbed with flannel until the leaves diverge ; again heat the glass rod very hot, rub it with fur, approach it to the disc and observe the increased divergence ; the divergence proves that the glass is negatively electrified.

Slight differences in the physical condition of bodies, affect the kind of electrification. If smooth glass be rubbed against roughened glass, the electrification of the smooth glass is positive, that of the rough negative.

Simultaneous and equal production of two kinds of electrification.—Make a flannel cap to fit the sealing-wax rod,



FIG. 164.

and attach a *thread of dry silk* to the cap (fig. 164). Dry the sealing-wax, flannel, and thread thoroughly. Turn the sealing-wax a few times in the cap, and place both on the disc of the electroscope; no divergence is noted. Again turn the flannel, draw off the cap *by the thread*, and place it alone on the disc, the leaves diverge, therefore the flannel is electrified. Remove the cap, touch the electroscope with the finger, and discharge it. Again turn the flannel cap on the sealing-wax, remove it, and show that the sealing-wax is electrified. Discharge the electroscope. Turn the sealing-wax in the flannel and place both on the disc; there is no divergence; withdraw the wax, leaving the flannel; the leaves separate; repeat, but this time withdraw the cap by the silk; again the leaves diverge.

When sealing-wax is rubbed with flannel, both the sealing-wax and the flannel are electrified.

Electrify the electroscope positively, by touching it with a glass rod rubbed with silk. Rub the sealing-wax in the cap, place the cap, being careful to move it by the dry silk thread, near, or on the disc; increased divergence shows that the electrification on the flannel is positive. Repeat the experiment, placing the rod alone near, or on the disc; the leaves collapse. Electrify the electroscope negatively, by means of a rubbed rod of sealing-wax. Turn the wax in its cap, remove the cap, and place the rod in the disc; further divergence shows that the rod is electrified negatively.

Similar experiments with other bodies, with similar precautions (note especially the use of dry silk thread), show that whenever two substances are rubbed together, one is electrified positively, while the other is electrified negatively. The amounts of each kind of electrification must be equal, seeing that when both are examined together, no effect is observed—that is, neither form of electrification can be in excess.

The student should revise the whole of his experiments, and attempt to determine the kinds of electrification upon each body used in the experiments.

Positive and negative electrification, parts of one phenomenon.—Whenever one form of electrification is produced, an equal amount of the other kind is produced. By taking suitable precautions we are able to show, as in the above experiment, that both are present; generally only one kind is apparent, and we are apt to consider the one kind, as the cause of the phenomena of attraction and repulsion.

Suspend a small pith ball *by a dry silk fibre*, rub the sealing-wax in its flannel cap, remove the cap by the silk thread, and let the sealing-wax touch the pith ball; the pith ball becomes electrified negatively; arrange so that the electrified pith ball is between the wax and the cap.

The space between the wax and the flannel, is now in such a state of strain, that the negatively electrified body moves towards the flannel. The motion is not due to the action of the wax alone, nor of the flannel alone; the movement of the pith ball is only possible, when both the positive electrification, and the equal amount of negative electrification, take part in the experiment. If the pith ball touch first the flannel, it moves from the flannel to the wax.

A similar experiment is shown in fig. 165. A light metal ball, C, fastened to a stiff fibre of shellac, is suspended by a thread of silk. A silk handkerchief, B, is rubbed on a clean, dry square of glass, A. If the ball touch the glass first, it moves from the glass to the silk; if it touch the silk first, it moves from the silk to the glass.

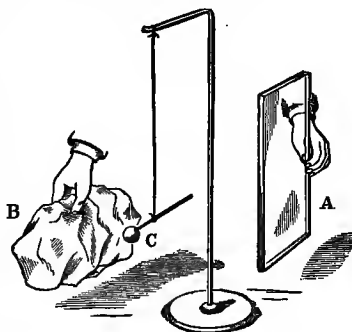


FIG. 165.

If we electrify a glass rod, it seems at first as if the positive electrification alone, was the cause of the attraction and repulsion; the negative electrification moves from the rubber

through our bodies to the ground, and distributes itself upon the near objects. Imagine the electrified glass suspended in a room, then an equal amount of negative electrification is distributed upon the walls, or upon the body of the experimenter, the space is in such a condition, that a light body positively electrified, moves, or tends to move, from the glass towards the wall, while one negatively electrified moves from the wall towards the glass.

EXAMPLES. II.

1. Describe a gold-leaf electroscope. How would you charge it negatively, and how positively?

2. Why can you not depend upon the collapse of the leaves, in determining the electrical state of a body brought near the disc?

3. A rubbed rod of vulcanite attracts light bodies. Does the attraction depend upon the electrification of the vulcanite alone?

4. If two insulated bodies A and B are rubbed together, and A becomes positively electrified, what is the electrical condition of B? (1) as to the kind of its electrification; (2) as to the amount of its electrification as compared with those of A.

5. If you rub together a stick of sealing-wax and a piece of flannel, and then put them both on an electroscope, the leaves do not move. What happens to the electroscope if you remove, (1) the flannel, (2) the sealing-wax? What would be the effect in each case of bringing near the electroscope a glass rod that had been rubbed with silk?

6. A rod of sealing-wax is rubbed with dry flannel. An uncharged pith ball suspended by a silk thread is attracted when the sealing-wax is brought near to it, but is unaffected by the flannel. Would you conclude from this experiment that when sealing-wax and flannel are rubbed together the sealing-wax only is electrified? Give reasons for your answer.

7. When a piece of sealing-wax and a piece of dry flannel are rubbed together, one becomes positively electrified and the other negatively electrified. When a piece of dry paper and a piece of india-rubber are rubbed together, one becomes positively electrified and the other negatively electrified. How could you find out which of the four things—sealing-wax, flannel, paper, india-rubber—are in the same electrical state?

Conductors and Insulators.—A pith ball, suspended from a gas bracket or ordinary support by a cotton thread, moves towards glass rubbed with silk, or sealing-wax rubbed with flannel; even after contact it again moves towards them.

Suspend a pith ball by a *dry silk fibre*. Fig. 166 shows a convenient arrangement. After contact with an electrified body, the pith ball is repelled.

*We were only able to show that the flannel was positively electrified when rubbed with sealing-wax, when we avoided touching

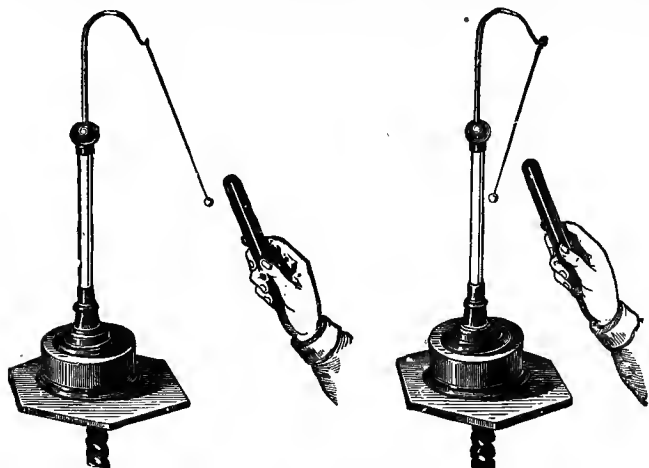


FIG. 166.

it with the hand, and moved it by the *dry silk thread*. The pith ball experiment, as far as repulsion is concerned, fails (try it) if the silk thread be *damp*, or if a *cotton thread* be used. The metal ball in fig. 165 was fastened to a rod of *shellac* suspended by *silk*. The rod of the electroscope is surrounded by *shellac*, by *glass*, and by *india-rubber*.

Cotton, our bodies, the metals, or damp silk threads allow the electrification to escape ; they are called conductors. Dry silk, shellac, dry glass, dry india-rubber, do not allow the electrification to escape ; they are called non-conductors or insulators.

Brass or other metal rods held in the hand and rubbed show no signs of electrification.

Insert a glass handle, or a rod of ebonite, in a brass rod, dry carefully both the handle and the rod, hold the compound rod by the handle, rub the brass with silk, and bring it near the disc of the electroscope ; divergence



FIG. 167.

takes place, showing that the brass is electrified. Fasten a brass ball to the end of a stick of sealing-wax, rub it on flannel and prove that it is electrified. It should attract pieces of paper, the suspended lath, and cause the leaves of the electroscope to diverge.

We infer that ebonite, sealing-wax, and dry glass are insulators.

That brass can be electrified is also easily shown, by lightly striking the disc of the electroscope with a silk handkerchief, when the leaves diverge. The electroscope is electrified by the rubbing of the silk against the brass. How is the brass insulated?

Insert a cork in one end of a glass tube, and a rod of wood or iron in the cork. Electrify the glass; the free end of the wood will attract pieces of paper, and when near the electroscope will cause a divergence of the leaves, even where the glass tube is at such a distance that it alone does not affect the electroscope.

- Cork, wood, and iron are conductors of the electrification.

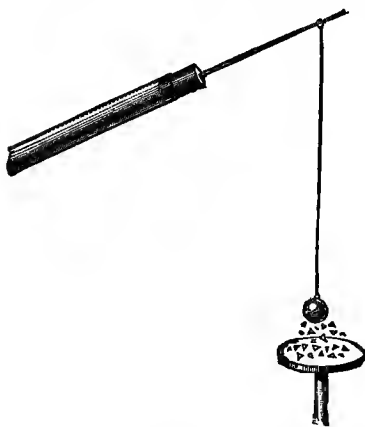


FIG. 168.

Insert the ebonite rod in the cork, pass it through a gas-flame to discharge it; electrify the glass.

The ebonite rod does not attract light bodies; it is an insulator.

Fasten a thin iron wire to the wood or metal rod inserted in a glass tube (fig. 168); attach a metal ball to the end, place underneath the ball pieces of paper, and excite the glass rod; the pieces of paper are attracted. A similar result is obtained

with a cotton thread. Show that the pieces are not attracted if a dry silk thread be used. Moisten the silk and show that attraction takes place.

Iron wire is a conductor, dry silk is an insulator, damp silk

is a conductor. The air is evidently an insulator, or we should be unable to retain electrification on the apparatus used.

Take a fine copper wire, a fine iron wire, and threads of silk and cotton, each about five yards long. Fasten one end of the copper wire to the disc of the electroscope; coil the other end loosely round the end of the glass rod; rub the rod with amalgamed silk, and let the loop slide down the rod. Notice the divergence of the leaves; in a similar manner use sealing-wax rubbed with flannel. Remove the copper wire and substitute the iron wire; again, the leaves diverge, but not so rapidly. With cotton thread the action is slower still; with dry silk thread there is no divergence; with a wet silk thread, however, a divergence is observable.

Careful experiments show, that there are no perfect insulators; all ultimately allow some of the electrification to escape. Bodies are divided according to their power of insulating in the following order:—

Insulators.—Shellac, resins, sulphur, wax, glass, silk, air and dry gases, lime.

Semi-conductors.—Ice, dry wood, powdered glass.

Conductors.—Cotton, linen, water, acids, charcoal, metals.

The insulating power of the different kinds of glass varies, and all glass becomes a conductor when very hot. Moisture readily condenses upon glass and destroys its insulating power; this is less likely to take place if it be coated with shellac varnish.¹

To insulate bodies.—Light bodies may be suspended by

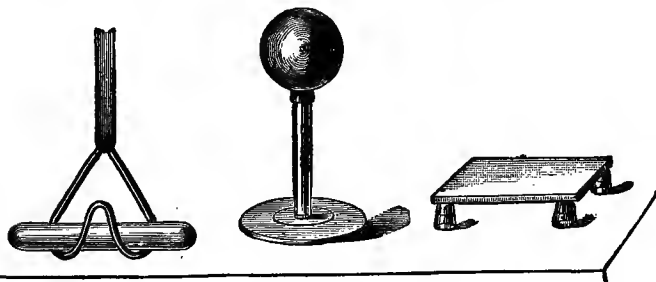


FIG. 169.

dry silk fibres, or by threads of shellac; heavier bodies can

¹ See Appendix.

be placed in a stirrup and suspended by a thin silk ribbon, or they can rest upon stems of varnished glass, shellac, sealing-wax, or upon rods of ebonite. An insulating stool is readily made by placing a dry mahogany board upon four *good* varnished glass tumblers (fig. 169). The greenish-coloured pickle jars are frequently better insulators than ordinary tumblers.

If a person stand upon the insulating stool and touch the electroscope-disc with his finger, we can electrify him by striking him with a silk handkerchief; the leaves diverge. Repeat the experiment when the person stands upon the floor. Why do the leaves not diverge?

Proof-planes.—Strong charges tear the leaves of the electroscope. We can take slight charges from a body by means of proof-planes. They consist of small pieces of good conductors (metal or gilt paper), attached to good insulating handles (rods of glass varnished, or rods of ebonite). A circular piece of gilt paper may be attracted with shellac to an ebonite handle, or a brass button or a penny may take its place (fig. 170).

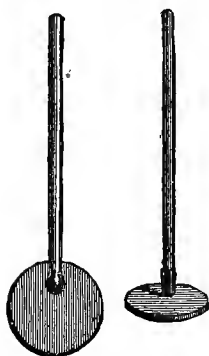


FIG. 170.

Excite the glass rod with amalgamed silk, hold the proof-plane by the handle, and draw it along the rod. The small conductor becomes electrified positively, by contact with the glass. Touch the disc of the electroscope with the piece of metal, and obtain a slight divergence of the leaves. Use similarly the electrified ebonite rod, &c., instead of the glass rod.

In the experiment illustrated in fig. 168, touch the metal ball with the proof-plane, carry the proof-plane to the disc, and prove that the ball is electrified.

EXAMPLES. III.

1. If you want to find out whether a body is electrified, by seeing how it acts on an electrified pith ball hung by a silk thread, why is it a surer test that the body is electrified if it repels the pith ball than if it attracts it?

2. A pith ball is suspended from a metal stand by a fine thread. If you have a strongly electrified glass rod, how can you find out whether the thread is a conductor or a non-conductor of electricity?

3. Describe experiments which show, that the terms vitreous electricity, and resinous electricity, are inappropriate.

4. A stick of sealing-wax, held in the hand, and rubbed with dry flannel is found to be electrified. A brass rod after being treated in the same way shows no electrification; how do you account for the difference?

5. Arrange the following substances in order of their conducting powers of electricity, putting the name of the best conductor first: air, copper, glass, iron, sea-water, shellac, pure water, wood.

6. You have several rods of unknown materials. Describe exactly experiments, which would enable you to distinguish those which are conductors of electricity from those which are non-conductors.

7. A muslin bag containing sulphur and red lead finely powdered is suspended by a silk ribbon so that it hangs within a metal vessel which stands on the cap of an electroscope. When the bag is jerked, the powders are shaken out through the muslin into the vessel and become electrified by friction. State and explain what effect (if any) is produced upon the electroscope?

8. An insulated conductor, A, is brought near the cap of a gold-leaf electroscope which has been charged positively. State and explain what will happen, (1) if A be unelectrified; (2) if it be charged positively; (3) if it be charged negatively.

9. A stick of sealing-wax is rubbed with dry flannel and held over a pith ball lying on a table. Why does it rise and why does it fall?

CHAPTER II

INDUCTION

The Electroscope.—The leaves of the electroscope diverge, before the approaching electrified body touches the disc ; they must, for the time being, be electrified. Re-read, and repeat the method of determining, by the electroscope, when a body is positively and when negatively electrified.

Touch glass rubbed with silk with the proof-plane, and convey the proof-plane to the disc ; as it approaches, the leaves diverge, the divergence increasing until contact is made. On touching the proof-plane with the fingers, or on drawing it rapidly through a flame, it loses its electrification, or it is said to be discharged. Repeat, giving successive charges to the electroscope until there is a fair divergence of the leaves.

Place the discharged proof-plane upon the disc of the charged electroscope ; partial collapse of the leaves takes place as it approaches, the collapse increases on contact. Remove the proof-plane and discharge it ; again place it on the disc, further collapse takes place.

In this way the electroscope can be totally discharged, and then no further effect is observed, when a non-electrified conductor is placed upon it. This collapse with a non-electrified insulated body takes place, whether the electroscope be charged positively or negatively. The electroscope, or any electrified body, gives part of its electrification to a non-electrified insulated conductor that touches it.

Discharge the electroscope, and then charge it positively. Draw the proof-plane along rubbed glass, and carry it to the disc ; a further divergence, that increases when contact is made, takes place. Discharge the proof-plane, and change it by drawing it along rubbed

sealing-wax, and carry it to the disc, partial collapse ensues. Discharge the proof-plane, recharge it by touching electrified sealing-wax and again touch the disc. Repeat this ; the collapse goes on until the leaves hang freely, that is, the disc is discharged. If you again repeat the experiment, the leaves begin to diverge again ; the electroscope becomes charged negatively.

The negative electrification of the proof-plane, neutralises an equal amount of the positive electrification of the electroscope or any positively charged conductor ; the proof-plane then becomes charged similarly to the conductor. Each small charge of the proof-plane acts in this manner, until the electroscope is completely discharged ; a further charge, charges the electroscope negatively and the leaves diverge. With a larger conductor than the proof plane, the partial collapse, total collapse, and divergence may take place at the first contact.

We conclude, that the accurate method for testing electrification, is to obtain further divergence as we *approach* the electrified body to the charged electroscope ; that collapse of the leaves may indicate either opposite or neutral electrification ; and that on contact, a collapse, followed by a divergence, may take place so rapidly, that it may suggest that an increased divergence has taken place.

Induction.—Charge the electroscope with positive electrification. Insulate a lath by placing it upon a dry tumbler (fig. 171) ;

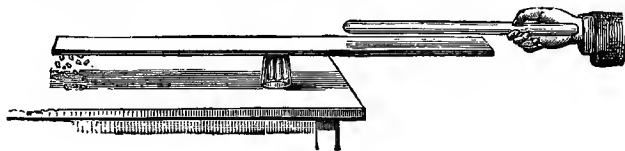


FIG. 171.

place scraps of paper under one end, and a rod of rubbed sealing-wax over the other end ; the pieces of paper are attracted, although there has been no contact. Remove the pieces of paper, but otherwise repeat the experiment ; touch the end of the lath that attracted the paper with the proof-plane, keeping the sealing-wax in position, and carry the proof-plane to the electroscope ; further divergence shows, that there is positive electrification at that end of the lath. Discharge the proof-plane by passing it rapidly through a flame.

Touch the end *under* the excited wax with the proof-plane and carry it to the electroscope; the leaves collapse, but this proves nothing, save that the electrification is not positive. Discharge the electroscope and then charge it negatively. Repeat the last experiment; further divergence shows that the end of the lath under the sealing-wax, possesses positive electrification. At or near the middle of the lath no form of electrification can be detected. Remove the wax, electrification cannot be detected on any portion of the lath.

When electrification is produced upon a body, by means of an electrified substance without contact, the body is said to be electrified by induction.

Repeat the experiments, using a rubbed rod of glass instead of sealing-wax, and show that the lath is positively electrified at the far end, and negatively electrified under the rod, and that there is no electrification at the middle of the lath.

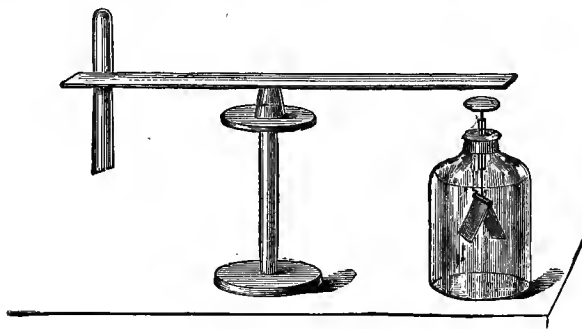


FIG. 172.

We may show the electrification of the lath by induction, by substituting the electroscope for the pieces of paper (fig. 172).

Giving the electroscope an initial, known charge, bring the excited electrified body to the far end of the lath, and determine the nature of the electrification, at the end over the electroscope.

A brass rod with rounded ends, or wood covered with tin-foil will yield better results, the electrification spreads more

easily upon it, metal being a better conductor of electrification than wood.

If a body charged positively, be brought near an insulated conductor, the near portion of the conductor becomes negatively charged, while the remote portion becomes charged positively; on removing the electrified body, the insulated conductor shows no signs of electrification. If a negatively electrified body be brought near an insulated conductor, the portion near the electrified body becomes charged positively, the farther end negatively; on removing the electrified body, the conductor shows no signs of electrification.

The reason, why the leaves of the electroscope diverge, when a rubbed rod of sealing-wax approaches is, that by induction the disc becomes charged positively, and the leaves negatively; and the leaves being similarly charged, repel each other.

To charge a body electrically by induction.—Arrange two insulated conductors in contact side by side (fig. 173). The balls being in contact, practically form a single conductor. Bring a positively electrified conductor near one, and show by the proof-plane, that the far ball is charged positively, and the near ball is charged negatively. Test the condition of the balls where they touch, no sign of electrification can be detected. Remove the electrified body, neither ball shows any sign of electrification.

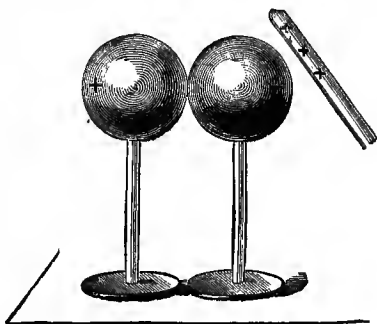


FIG. 173.

Keeping the rod in its place, separate the balls, and then remove the rod. Test each ball separately with the proof-plane; the far ball remains charged positively, the near ball negatively. Instead of using the proof-plane, bring each insulated conductor in turn near an electroscope, and obtain divergence of the leaves. (How must the electroscope be previously charged in each case?) Let the balls touch again; just before contact a spark passes; after contact neither form of electrification can be detected on either.

While the electrified body is in position, touch the far ball

momentarily with the finger, remove the finger and then the rod; test the nature of the electrification on both balls, both will be negatively electrified. (How would you charge both positively?) Repeat, but touch the near ball, again both remain negatively electrified. Converse results are obtained if rubbed vulcanite, sealing-wax, or shellac be used in the place of the glass rod.

To vary the experiment use an insulated cylindrical conductor; while an electrified glass rod is near, touch the cylinder, remove

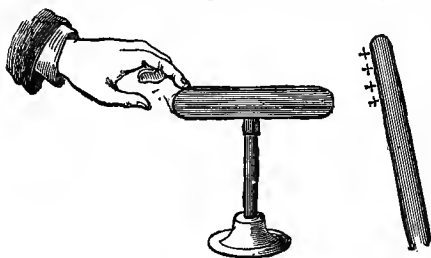


FIG. 174.

first the finger, then the rod (fig. 174). Test the cylinder, it will be found to be negatively electrified. Repeat, but touch the end of the cylinder near the rod.

When we touch the cylinder, the cylinder, our body, and the earth form one conductor; the near portion (that is the cylinder) becomes negatively electrified, the body and the earth positively electrified. On removing the finger, the cylinder remains negatively electrified.

By using a rod of sealing-wax or vulcanite we can similarly charge a body positively. It is not necessary to touch the balls or cylinders at the side remote from the charged body; the body and the earth will always form the distant portion, and on removing the finger the insulated conductor remains charged. Instead of using our finger and body to connect the insulated conductors to the earth, it is often convenient to use a chain or wire.

To charge an Electroscope by Induction.—(1) (fig. 175). The uncharged leaves hang side by side. (2) Bring a rod charged positively near the disc. The disc becomes negatively, and the leaves positively electrified by induction, and diverge. (3) Touch the disc with the finger; the disc, the leaves and the finger become negatively charged, the body and earth positively; the positive electrification of the rod neutralises the equal amount of negative electrification on the electroscope, and the leaves collapse. (4) Remove the hand;

the negative electrification of the electroscope is acted upon by the positive electrification of the rod, and the leaves are un-

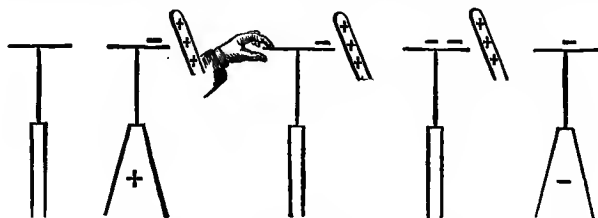


FIG. 175

affected. (5) Remove the rod; the leaves diverge, as the whole electroscope is charged with negative electrification.

The student will remember, that the leaves do not diverge because negative electrification repels negative electrification. When the rod is removed, the negative electrification on the disc and gold-leaves, induces positive electrification somewhere, on the side strips of tinfoil (fig. 161), on the walls, or on the glass of the electroscope. Each leaf is between the other leaf negatively electrified, and a positively electrified body (the glass or the wall); it moves in the electrified space, away from the leaf to the glass.

If you insulate the electroscope, and connect the disc to the strips at the side by wire (fig. 165), you may charge the disc as you please, but no repulsion takes place, because each leaf is between two bodies, each charged similarly with positive electrification.

EXAMPLES. IV.

1. How would you charge a gold-leaf electroscope positively, (*a*) by the aid of a body positively electrified, and (*b*) by the aid of a body negatively electrified.

2. An electroscope is charged negatively, and an insulated brass ball is brought near the disc; what conclusion do you come to, as to the electrification of the ball (*a*) when the leaves slightly collapse, and (*b*) when they slightly diverge?

3. A stick of sealing-wax, having been rubbed with flannel, is found to be negatively electrified. How, by means of it, would you charge a proof-plane with positive electricity? What would you require instead of the sealing-wax to charge the proof-plane negatively?

4. A brass rod is supported horizontally by a dry glass stem, and a large strongly electrified metal ball is brought near one end of the rod (but not near enough for a spark to pass). The rod is then touched for an instant by the end of an earth-connected wire, and afterwards the ball is removed. Will it make any difference in the final electrical state of the brass rod whether the wire touches it at the end nearest the ball, at the end farthest from the ball, or at the middle? Give reasons for your answer.

5. Two insulated metal spheres are brought so as to touch one another. A positively electrified glass rod is brought near to one of the spheres and, while it is there, the other sphere is taken away. Then the glass rod is taken away. On bringing the spheres near to each other again, a spark passes between them. Give the reason for this?

6. If an electrified piece of metal is made to touch a gold-leaf electroscope, the leaves separate, and, on taking the metal away, they remain separate. But if the electrified metal is only brought near to the electroscope, and then taken away, the leaves separate, when the metal is near, but fall together when it is taken away. Why is there a lasting effect on the gold leaves in one case, and only a temporary effect in the other case?

Attraction and Repulsion.—We can now understand more clearly, what takes place, when a positively electrified body attracts a pith ball or other light body.

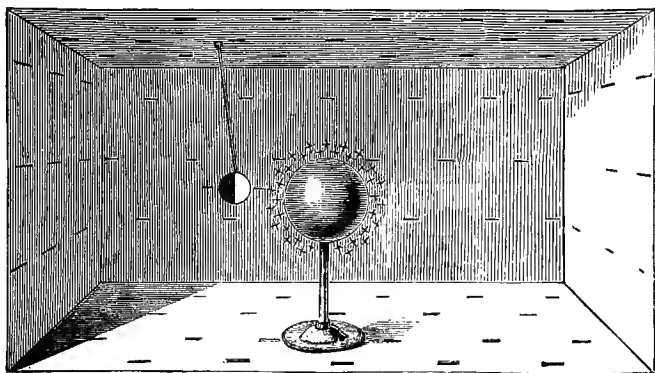


FIG. 176.

Imagine a positively electrified insulated body (represented in fig. 176, by the large sphere) and a small insulated pith ball

in a closed conductor (an ordinary room). The positive electrification on the sphere induces an equal amount of negative electrification upon the walls of the room, the insulator (the air) is in a state of strain, and any body placed in it will be electrically affected. The pith ball is in a space between the charged sphere and a portion of one of the walls ; *the negative electrification on this portion of the wall will be very small in amount compared with the positive electrification on the sphere.* The side of the pith ball near the sphere, becomes charged negatively by induction, an equal positive charge being on the other side. (How would it be charged if the pith ball were not insulated ?) The side negatively electrified is attracted by the sphere, the other side is repelled ; if this were all that took place attraction would ensue, seeing that the negative charge is nearer than the positive charge. A similar action upon the pith ball takes place, due to the negative electrification on the wall ; the result of this alone would be to attract the pith ball to the wall. On account of the greater amount of electrification on the sphere, compared with that on the portion of the wall, and also upon the nearness of the pith ball to the sphere, the attraction of the sphere is greater than the attraction of the wall, and the pith ball moves to the sphere.

The greater amount of the attraction and repulsion, is due to the action of the sphere; this has led to the action being described as due to the sphere alone. If we connect the sphere and the walls with a wire or other conductor, and the whole be insulated, no matter how we charge the sphere, it will not attract a pith ball or any other suspended body.

The electrification is on, or near, the outer surface of a conductor.—When a hollow insulated conductor with an aperture, is charged positively or negatively (fig. 177), a proof-plane, c , can collect a charge from the exterior, but not from the interior.

Electrify a hollow insulated metal cylinder, touch the inside with the proof-plane, and carry the plane to the electroscope ; no charge can be collected from the inside (fig. 178) ; show that a charge can be obtained from the outside.

A gauze net, held in an insulated handle, is charged ; the proof-plane is able to collect a charge from the outside, but not from the

inside. Take hold of the two dry silk threads, and turn the net

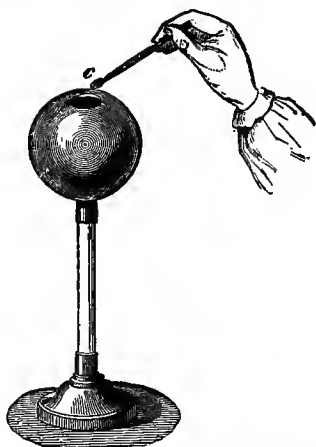


FIG. 177.

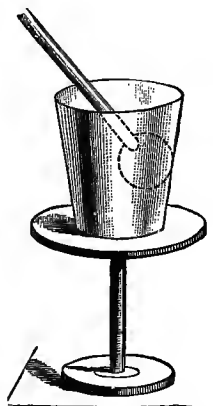


FIG 178.

outside in; the charge can again only be collected on the outside (fig. 179).

If the proof-plane or other body inserted into a hollow conductor be electrified, then by induction, electrification of opposite kind will be found on the interior; a charge is also obtained if the proof-plane be large and project beyond the aperture, the plane then forms part of the outside surface.

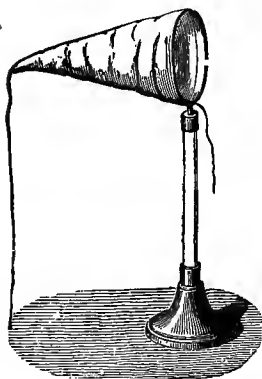


FIG. 179.

The electrification might quite as accurately be described as residing on the film of air nearest to the conductor, as on the exterior of the conductor itself.

Electrical Density. Points.—In electrical apparatus, the conductors are rounded, points are avoided.

Charge an insulated pear-shaped conductor (fig. 180) electrically,

either by induction, or by using the electrophorus or electrical machine; test parts of the surface with the proof-plane.

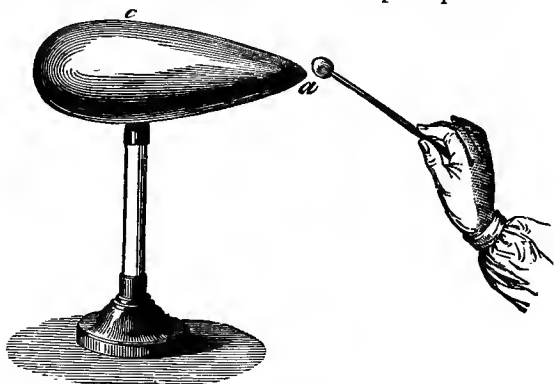


FIG. 180.

On carrying the plane to the electroscope, it is found that the greatest amount of electrification, can be taken off by the plane at *a*, where the curvature is least, and the least amount at *c*, where the curvature is greatest.

The amount of electrification per unit of surface, is called the electric density of that surface. The experiment above shows, that the electric density at the part *a* is greater than at *c*. If *a* be reduced to a point, the density may become so great, that the electrification passes away in a stream from the conductor to the particles of air, and the conductor is soon discharged.

If an unelectrified insulated conductor be provided with a point, and an electrified body charged—say, negatively—be brought near the point, by induction the point becomes charged positively, the density becoming so great that a silent transfer of the electrification takes place, the negative passing to the conductor, while the positive passes to the electrified body. On removing the electrified body, the conductor is charged with negative electrification; in a short time the conductor discharges itself by the point.

We may graphically represent the electric density on insulated conductors, by drawing dotted lines around them (fig. 181), the

comparative distance of the line from the surface indicating the comparative electric density. On the surface of a sphere the den-

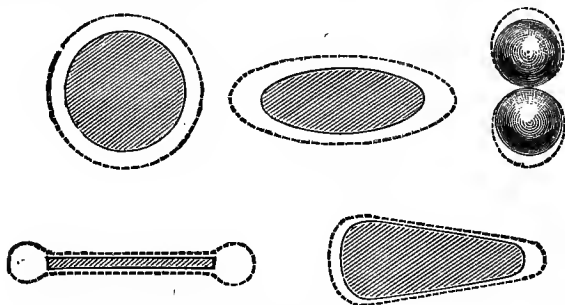


FIG. 181.

sity is uniform, on a disc it is greatest at the edges. The student should draw such figures for various forms of conductors.

EXAMPLES. V.

1. Under what circumstances can you get a charge on a metal ball, hanging by a silk thread, by touching therewith the inside of a metal jar?

2. A pewter pot is insulated and electrified. If you touch it at different parts with a penny stuck to the end of a rod of sealing-wax, what part of the pot will give the greatest quantity, and what part the least quantity of electricity to the penny?

3. A deep metal pot positively electrified, stands on a glass stem. A metal ball hung by a silk thread is put in contact with a gold-leaf electroscope after being made to touch—(a) first the inside, then the outside of the pot; or (b) first the outside, then the inside of the pot. State and explain the effect on the electroscope in each case.

4. To protect a gold-leaf electroscope from being acted on, when an electrical machine is at work near it, it is sufficient to cover the electroscope with a thin cotton cloth. How is this?

5. The extremity B, of a wire A B, is attached to the plate of a gold-leaf electroscope. By means of an insulating handle, the other end A is placed in contact, first with the blunt and then with the more pointed end of a pear-shaped insulated and electrified conductor. Describe and explain the movements of the leaves of the electroscope.

6. An orange, into which a sewing needle has been stuck, point outwards, is suspended by a dry silk thread. A charged body is brought near to it, first, opposite the point of the needle; second, opposite the side remote from the needle. State and explain the electrical effect in each case.

7. An insulated electrified conductor can be discharged by bringing near it the point of a sharp needle held in the hand. Explain this.

CHAPTER III

POTENTIAL—MACHINES

Potential.—If an insulated conductor be electrified positively, and we touch it, or connect it to the earth by a wire, there is a transference of positive electrification along the body, or along the wire to the earth, or we may say there is a transference of negative electrification to the conductor. This transference continues until the conductor shows no signs of electrification ; it is discharged. The air (an insulator) between the conductor and the earth was in a state of strain before we connected the conductor to the earth, and there was a tendency for the positive electrification to pass to the earth ; the transference became possible when a conducting body was introduced. Whatever produces, or tends to produce, a transfer of electrification is called **ELECTROMOTIVE FORCE**.

If we have two insulated spheres—one, say, 6 inches in diameter, the other $\frac{1}{2}$ -inch in diameter—and we charge the large sphere by holding it against the prime conductor of an electrical machine, while we make, say, 6 turns, and charge the small sphere, while we make, say, 3 turns, the large sphere contains a greater amount of electrification ; yet, if the two be brought together, the electromotive force tends to produce a transfer of electrification, from the small to the large sphere, and the transfer takes place, if they be connected by a wire, or if they touch each other ; or the strain may be so great, when they are brought near to each other, that the electrification passes across the intervening air, carrying with it the pieces of incandescent metal—that is, an electric spark passes.

The condition of a body with regard to its electrification that determines the direction of the transference of its electrifica-

tion, is called its **POTENTIAL**. The small sphere is at a higher potential than the large sphere.

Imagine two cisterns of water connected by a flexible pipe, one containing 2 gallons, the other 1 gallon. The direction of the flow is determined, not by the amount of water, but by the level of the water in the cisterns. If the smaller be raised, the water flows to the larger until the level in each is the same ; if the larger be raised, the water flows from the larger to the smaller. The level determines the flow of water, and in this respect is analogous to potential. The level gives no inference about the quantity of water in the cistern, neither does the potential state anything about the quantity of electrification in either of the spheres. If we charge an insulated body negatively, the space around it, is in such a condition, that there is a tendency for a transference of positive electrification from the earth to the body ; the transference will take place if we connect it with the earth ; the potential of the earth is higher than that of the insulated body. This is analogous to the fact that water will tend to flow from the sea-level to any point below the sea-level ; it will flow if the sea and the point be connected by a pipe.

Electrification flows from a body at any potential to one at a lower potential.

Another analogy may be found, in the cases of bodies at different temperatures. Heat flows from a body at a high temperature to a body at a low temperature. The body at the high temperature, may contain an amount of heat, equal to that contained by the body at the low temperature, a greater amount of heat, or a less amount of heat. The direction of the flow of heat depends upon the temperature, and not upon the amount of heat.

The explanation means no more than it says. It does not state, for instance, that wherever there is negative electrification, the potential is lower than the earth, nor where there is positive electrification it is higher than the earth.

In figs. 173, 174 the proof-plane can collect positive electricity at one end, negative electricity at the other, while it is unable to collect any at the middle of the conductors. If we connect the conductors at any point, by a wire to the earth, there

is a transfer of electrification to the earth along the wire. Every part of each conductor is at a potential above the earth.

For purpose of reference, we define the zero of potential as the potential of the earth ; if electrification flows, or tends to flow, from a body to the earth it is at positive potential ; if it flows, or tends to flow, from the earth to the body, the body is at negative potential ; if, on connecting the body to the earth, there is no transfer of electrification, the body is at zero potential.

The space around a rubbed stick of vulcanite, is in such a condition, that there is a tendency for positive electrification to flow from the earth to the vulcanite ; the vulcanite is therefore at negative potential. The nearer the vulcanite the greater the tendency, the negative potential then decreases from the vulcanite to the earth ; we do not state however, that the decrease is proportional to the distance ; we do not know that the potential at four inches from the rod, say, is half of what it is at two inches. Into this electric field let us introduce the ELECTROSCOPE.

Positive electrification is transferred from the leaves to the disc ; the leaves diverge, being charged with negative electrification, the disc is charged with positive electrification. The potential of the whole of the conducting parts of the electroscope is the same, otherwise there would be a further redistribution ; it is at negative potential ; if we touch it anywhere, electrification flows from the earth to the electroscope, and its potential now is zero, otherwise there would be a transfer from the earth to the electroscope, or from the electroscope to the earth. Remove the hand, the electroscope is charged with positive electrification, but in the presence of the charged rod, it is still at zero potential, because if we again connect it to the earth with a fine wire, there is no transfer of electrification. Remove the rubbed vulcanite ; the electroscope is charged positively and, in the absence of other electrified bodies, is at positive potential. If now we connect it to the earth, electricity flows from the conductor to the earth, and its potential again becomes zero.

The Electrophorus.—In its simplest form, the electrophorus consists of two parts : a cake B (fig. 182) made of vulcanite, resin, indiarubber, or other resinous substance ; and a flat metal plate A, to which is attached an insulating handle of glass or ebonite. The cake is struck or rubbed with fur, and thus becomes negatively electrified ; by induction the part of the table or surface on which it

rests becomes positively electrified (fig. 183). On placing the plate upon the cake there is not perfect contact, the cake and plate only touch at a few points, a layer of air being between at other parts ;

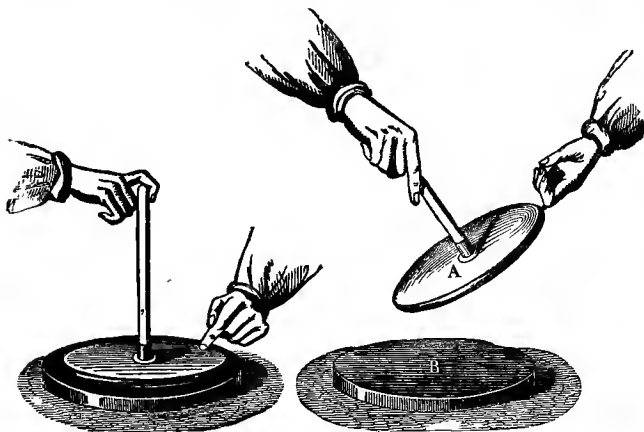


FIG. 182.

the negative electrification on the upper part of the cake, acts by induction upon the cover, the lower surface being positively electrified while the upper is negatively electrified, and the potential falls

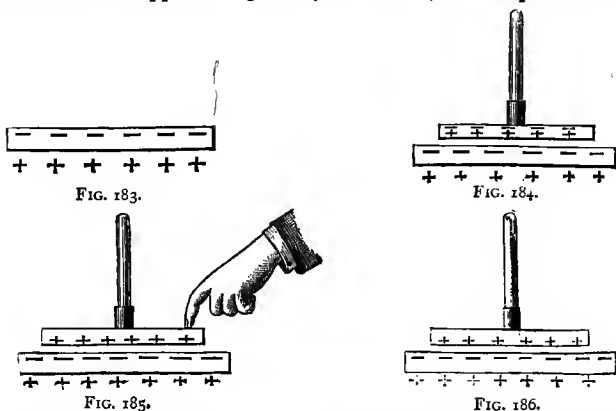


FIG. 183.

FIG. 184.

FIG. 185.

FIG. 186.

below zero (fig. 184). If now the plate be touched (figs. 182, 185), negative electrification will escape while positive electrification will take its place ; there will be an excess of positive electrification

attracted by the opposite charge on the cake, to the underside of the cover, the potential rises to zero ; on removing the finger, the cover remains positively charged but at zero potential (fig. 186). On raising the cover by its insulating handle, the charge distributes itself over the plate, and the potential rises above zero. If now we present any conductor at a lower potential to it (fig. 182), a spark passes, and the potential falls.

The cake remains in the same condition as after rubbing, and the cover may again be charged, and thus a series of sparks obtained. The spark is neither electrification nor electricity ; before contact, the positively charged lid, charged the knuckle negatively by induction ; the tendency for the electrifications to combine was so strong, that part of the lid was heated to incandescence, was torn from the lid, and formed the conductor for the passage of the electrification.

It may appear to the student that the electrophorus is an inexhaustible supply of energy ; he should remember that over and above the work necessary to lift the plate when the cake is not electrified, an additional amount of work is necessary to lift the plate when the cake is electrified ; this additional work is the source of the energy.

The Cylinder Electrical Machine.—A cylinder of glass, A

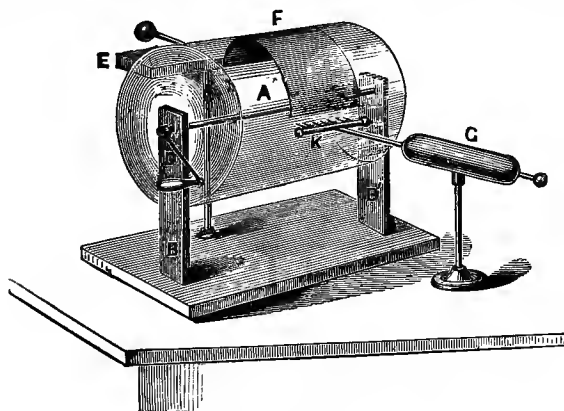


FIG. 187.

(figs. 187, 188) turned by a handle, D, rubs against a cushion

of amalgamated silk, *E* ; the glass becomes positively electrified, the silk negatively electrified. The rubber is usually connected

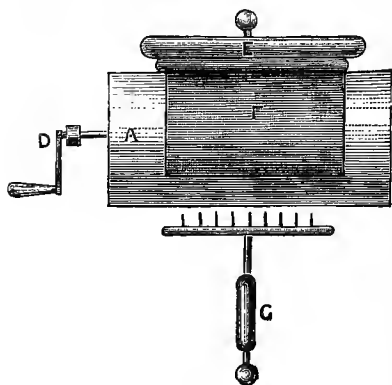


FIG. 188.

to the earth by a conductor, and thus shows no signs of electrification ; the rubber might be insulated and the conductor, *G*, joined to earth. To the rubber is attached a silk flap, *F*, to prevent loss of electrification. *G*, an insulated cylinder made of brass, or metal, or wood covered with tinfoil, is called the prime conductor ; the larger it is, the greater will be the charge

obtained ; at one end of *G* is a metal rod carrying a comb, *K*, with fine brass points. The electrified glass comes opposite the points ; by induction the points become strongly charged negatively (fig. 189). The negative electrification passes from

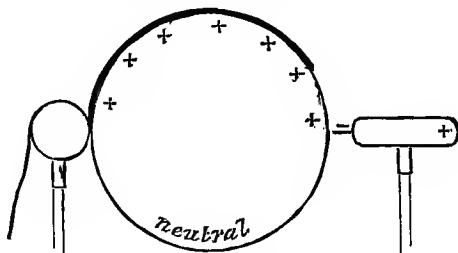


FIG. 189.

the points to the glass, while positive electrification passes from the glass through the comb to the conductor, which thus becomes charged positively, an equal amount of negative accumulating on the walls of the room. The negative electrification, passing from the comb to the glass, renders the glass neutral as regards electrification ; it becomes again charged

with positive electrification as it rubs against the cushion, and thus a continual supply of positive electrification is given to the prime conductor.

The maximum potential of the prime conductor will be due to the difference of potential attainable by the friction between glass and amalgamed silk; with other materials the potential will change. As the bodies we bring near the prime conductor are generally at zero potential, we obtain the best effects by keeping the rubber at zero, the highest practical potential; that is, we connect it with the earth.

The plate electrical machine.—The action of the plate machine is the same as that of the cylinder machine; a glass or ebonite plate, A (fig. 190), takes the place of the cylinder; there are generally two rubbers and two sets of collecting points, B, each connected with the prime conductor, that consists of the curved brass rods and the knob C.

The energy of the machines is obtained from the work done, in turning the glass, a large part of such work is lost in friction.

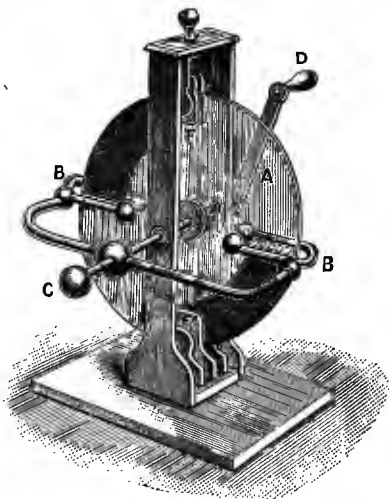


FIG. 190.

Origin of the Leyden jar.—The following electric machine was in use in Leyden in 1745; a revolving sphere of sulphur rubbed against the dry hands of the experimenter (fig. 191); the sphere was connected by a chain, with a conductor of brass suspended by dry silken cords. A pupil, wishing to electrify water in a jar, held the jar in his hand, and let a chain from the conductor dip into it; after some time he touched the con-

ductor with his other hand and received a severe shock. This gave rise to the Leyden jars.

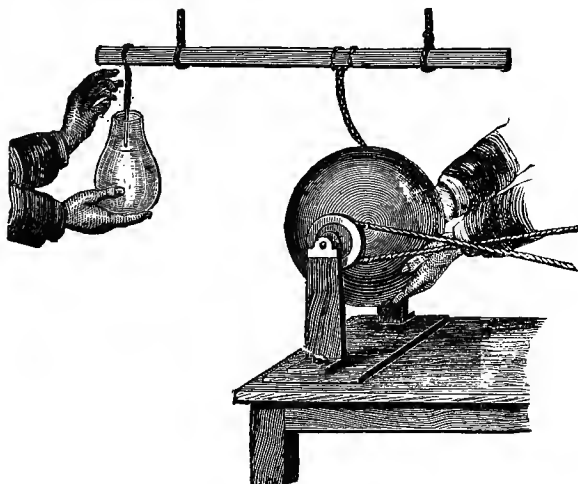


FIG. 191.

Imitate the experiment, using a simple Leyden jar shown in fig. 192. A nail passes through a dry cork, and dips into the water in the bottle. Dry thoroughly the outside of the jar. Hold it in the hand, and press the nail-head against the prime conductor of the machine. After the jar is charged, touch the nail-head with the finger of the other hand.



FIG. 192.

Explanation of the Leyden jar.—Electrify an insulated brass disc, and fix it about $\frac{3}{4}$ " above the electroscope, touch the top with the finger, and remove the finger; the leaves do not diverge (see fig. 175); interpose a dry thick plate of glass between the disc and the top of the electroscope, without touching either. The leaves diverge with positive electrification. Ebonite, solid paraffin, and

india-rubber give similar results.

Induction acts better across glass, ebonite, and india-rubber than across air.

When an insulated conductor is charged, say, positively, an

equal amount of negative electricity is distributed upon the walls of the room, the body of the experimenter, and upon neighbouring conductors ; if the latter be very near compared with the others, the induced charge will be practically upon the neighbouring conductors.

Dry carefully a varnished pane of glass, rest it upon an insulating stand, and place upon it a square of tinfoil smaller than the glass. Charge the insulated tinfoil with the electrophorus. It soon becomes charged positively. The bulk of the equal negative charge, being on the surface of the table, we may neglect that on the walls of the room. If we bring the finger near the tinfoil, it is charged negatively by induction, and at a short distance a very small spark passes.

Rest a piece of tin, B, the size of the tinfoil, on the insulator ; place the glass on this and the foil, A, above ; again charge the tinfoil (fig. 193) ; an equal negative charge will be on the tin, and the tinfoil receives a greater charge than before ; touch the tin or connect it with the table. The upper tinfoil is now able to receive a few more sparks. The tin is usually placed upon the table, and is then in constant electrical contact with the earth.

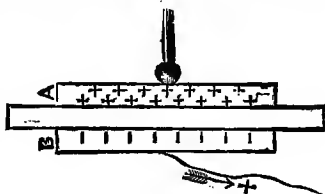


FIG. 193.

The positive electrification, acts by induction across the glass, and induces negative electrification on the surface of the tin near the glass, positive electrification being in the other side. The amount of the + ve charge given to the tinfoil is limited to the amount of the induced -ve electrification on the sheet of tin ; when we touch the tin, there is a transfer of the positive electrification to the earth ; the tinfoil is thus able to receive a further positive charge, as an equal negative charge readily flows from the earth and distributes itself on the tin. By connecting the tin to the earth, we have increased the capacity of the tinfoil, and its capacity is also greater than if air were between the foil and the tin, seeing that induction takes place better across glass than air.

If we now bring the finger, which is electrically connected with the sheet of tin, near the tinfoil, the finger becomes charged

negatively by induction, the tension is greater than before, and we feel a distinct shock. It is evident that the greater the area of the tinfoil, the greater will be the capacity.

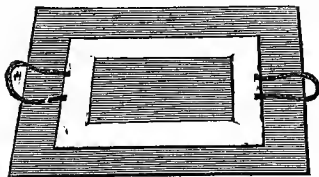


FIG. 194.

For experimental purposes, it is convenient to make the tin larger than the glass (fig. 194), the glass can be lifted by dry silken handles. It is then easy to show that the charge A re-

ceives, depends upon its distance from B. To obtain the greatest charge we place A as near as possible to B.

The Leyden jar.—A glass vessel is lined inside and outside to a certain height with tinfoil (the two metal plates of the pane). Glass is used because induction acts better across it, than any other common substance ; it also resists the transference of the electrification better than air. A metal knob is joined to the inside coating by a conductor, such as an iron or brass rod ending in a flexible chain, that press against the interior coating. The rod must be perfectly insulated ; it passes through dry varnished mahogany (a bad conductor) to keep it off the sides of the glass. The glass must be kept dry ; this is better attained by varnishing the uncovered part.

Leyden jars frequently act indifferently ; the chief causes are : (1) the kind of glass may be a bad insulator ; (2) the insulation of the wood or cork may be defective, or the surface of the glass becoming coated with moisture, the two coverings are electrically connected, and the jar is discharged.

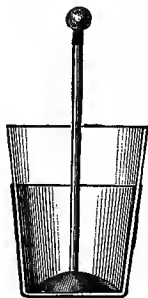


FIG. 195.

The best form is an open jar. Coat the bottom and the inside to within 2" of the top with tinfoil, connect the knob carefully, and fill up with wax to keep the knob in its place (fig. 195) ; coat similarly the outside. Varnish the uncovered part of the glass with shellac varnish.

To charge and discharge the Leyden jar.—The jar is charged by connecting one coating with the earth, and presenting the other to the prime conductor of a machine, or by giving the other successive charges from an electrophorus ; for

convenience, the *outer* coating is earth-connected, either by letting it rest on the table or by holding it in the hand. A well-made jar should retain its charge for some time, although in the best a slow leakage takes place.

The jar is discharged by connecting the two coatings, if it rest on the table and the connection be through the table, the floor, and our body, we experience a shock ; usually a thick rod or wire with a knob at each end, is used as the DISCHARGER, the wire is insulated from the hand, one knob touches *first* one coating, and the other knob is then presented to the other coating.



FIG. 196.

A cheap form of discharger is shown in fig. 196. The ends of a thick piece of wire are inserted into small brass or leaden balls, the wire is fixed securely into a thick test-tube with cement. For ordinary experiments a yard of thick telegraph wire coated with gutta-percha answers well, the insulation of the gutta-percha is sufficient, and the wire can be bent into any desired shape.

A Leyden jar with movable coatings.—B (fig. 197) is a glass that fits into a tin cup c; a tin vessel d, electrically connected

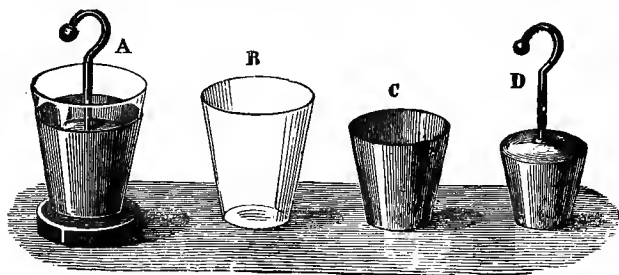


FIG. 197.

with a knob fits into B. The Leyden jar, A, is built up from these parts, and is charged in the usual way. If we hold it in one hand and touch the knob, the shock informs us that the jar is in good order. Again charge it and place it upon an insulator (a sheet of vulcanite). Lift out D and place it upon the table, a

very small charge comes with it and an equal charge can be obtained from the outside coating ; now remove B, and finally place c on the table. We can handle the parts without experiencing any shock. Replace c on the insulating stand, insert B and finally D. On connecting the inside and outside coatings, a strong shock is experienced.

Seeing that c and D have been connected to earth, we can only conclude that the electrification resides in the glass and not on the metal coatings ; the glass is in a state of strain. To discharge the jar, it is however necessary to have the metal coatings.

If a jar be discharged, and in a few minutes the coatings be again connected, another slight shock is experienced ; after a short time another can be obtained ; the glass is unable to relieve itself entirely of the strain when connection is first made.

Atmospheric Electricity.—The analogy between lightning and thunder, and the electric spark and the accompanying noise was observed by the earliest philosophers. Franklin suggested that a thunder-cloud might be discharged by a long pointed iron wire connected with the earth (the explanation is given on p. 185) ; this experiment was carried out. Believing that the thunder-cloud was an electrified body, he attempted to discharge it, by using a kite with a pointed wire attached ; the kite was held by ordinary thread attached to a key, a silken cord being interposed between the key and the hand ; when the thread became *damp* during a shower he was able to charge a Leyden jar from the key. The use and reason for the various parts in the kite experiment, can be filled in by the student.

A cloud at a potential above or below that of the earth, acts by induction upon the earth and neighbouring clouds, inducing electrification of an opposite kind. The difference of potential may become so great, that discharges or flashes of lightning take place between cloud and earth or cloud and cloud, accompanied by thunder due to the mechanical disruption done by the spark, as it passes through the air. The electric density will be greatest on parts that project, such as houses, trees, and tall chimneys ; for this reason lightning

frequently strikes such objects. As has been seen, if the projecting object end in a point, a silent discharge takes place, which wholly or partially neutralises the electrification of the thunder-cloud ; even if the lightning strike a stout pointed metal conductor, terminating under ground in large plates of metal, the conductor offers but a small resistance to the electrification, and the building to which this LIGHTNING-CONDUCTOR is attached escapes. When the discharge takes place through a chimney, house, or tree, the resistance offered to the electrification is so great, that the object is frequently shattered.

When a thunder-cloud is over a person, a shock, that is sometimes fatal, is felt, even when lightning does not pass between the cloud and the earth in that particular place. The cloud induces a charge on the body, and when lightning passes from the cloud to the earth at some distance away, this charge is suddenly released and escapes to earth ; it is called the *return shock*.

EXAMPLES. VI.

1. Say exactly what you must do to get a succession of sparks from an electrophorus.

2. A piece of dry brown paper laid on a warm metal tray is rubbed with catskin. The tray is then placed on a dry glass tumbler, and the brown paper is removed. Explain how it is that you can now get a spark on bringing your knuckle near the tray.

3. A little pith ball rests on a brass plate provided with a glass handle. The two are placed on a cake of resin which has been rubbed with a catskin. When the plate is touched by the finger and then lifted by the handle the pith ball jumps off the plate. Why ?

4. Describe a Leyden jar and the method of charging it.

5. Describe fully, how you would charge a Leyden jar from the positive conductor of an electrical machine, so as to get at will either a positive, or a negative, charge on the inner coating.

6. On touching the knob of a charged Leyden jar standing on the floor or a common table, you get an electric shock ; but if either you, or the jar, stand on a dry cake of resin, you do not get a shock on touching the knob. Explain this.

7. The inner coating of a Leyden jar, is connected by a wire with the prime conductor of an electrical machine, and also with a gold-leaf electroscope. If the jar rests upon a sheet of glass, a quarter of a turn of the machine produces a large divergence of the leaves of the electroscope. If

the glass be removed ten turns of the handle are required to produce the same deflection. Explain this.

8. One person holds a charged Leyden jar in his hand by its outer coating, and another holds similarly an uncharged jar. What happens when the knobs of the two jars are brought together.

9. When the handle of an ordinary frictional machine is turned, sparks can be drawn from the prime conductor. Explain carefully how the prime conductor becomes charged with electricity.

10. In the common plate or cylinder electrical machine, the conductor is of rounded shape at all parts, except where it comes nearest to the plate or cylinder ; but here it is provided with sharp projecting points. What reason is there for this arrangement ?

11. How is it that in damp weather an ordinary plate electrical machine will not work well ?

12. Two pith balls suspended, one by a damp cotton thread, the other by a dry silken thread, are each of them touched by the knob of a charged Leyden jar, which is held in the hand by its outer coating. Will there be any difference between the behaviour of the two balls ? If so, what difference, and why ?

13. An electrified metal ball is introduced into a dry glass tube closed at one end, and then the tube being held in the hand is brought near to the cap of an electroscope. What will the effect on the electroscope be if the exterior of the tube (1) is, (2) is not, covered with tinfoil ?

14. Two pith balls hang side by side by two damp cotton threads. State and explain what happens when an excited glass rod is brought gradually near the two balls from below.

VOLTAIC ELECTRICITY



CHAPTER I

THE VOLTAIC BATTERY

The Simple Cell.—On connecting a body at any electrical potential, to a body at a lower potential, with a wire, there is a transfer of electrification along the wire, the transfer being regarded as from the higher potential to the lower potential; in Frictional Electricity, several examples of such transference have been noticed. The transference takes time so short, that it may be regarded as being instantaneous; when the potentials become equal, there is no further transference. If therefore we could keep the difference of potential constant, we should have a continuous transference of electrification, called a *current*.

Dip a rod of *pure* zinc into dilute sulphuric acid; no effect is observed. Dip a rod of *ordinary* commercial zinc into the same acid; an effervescence takes place, hydrogen is evolved, the zinc rod wastes, and forms sulphate of zinc; this is an example of chemical action.

If rods or plates of *pure* zinc and copper be placed in dilute sulphuric acid so that they do not touch, no chemical action takes place, nor can any difference of potential ordinarily be observed between the copper, acid, and zinc. If a piece of copper wire be joined to each plate (fig. 198), that joined to the zinc *c* is at negative potential, while that joined to the copper *c'* is at positive potential; the difference of potential produces a tendency for a transference of electrification from *c'* to *c*.

That which moves, or tends to move, a mass is called a force; whatever moves or tends to move electrification is called **ELECTROMOTIVE FORCE**; although it is not a force at all in the ordinary sense, seeing that electrification is not a material substance. The letters **E.M.F.** will be used for electromotive force. If the two wires *c* and *c'* be joined (fig. 199), a current, due to

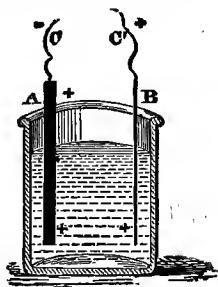


FIG. 198.

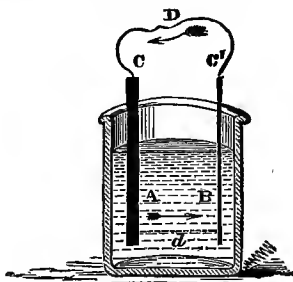


FIG. 199.

the **E.M.F.**, flows from the copper to the zinc outside the liquid and from the zinc to the copper inside the liquid; bubbles of gas, found to be hydrogen, rise from the copper; the zinc is gradually eaten away, and sulphate of zinc dissolves in the solution. When the terminals *cc'*, are separated—that is, when we break the circuit—the action ceases.

The wire joined to the zinc plate is called the negative or — pole, while that joined to the copper is called the positive or + pole.

The difference of potential between the terminals is the cause of the **E.M.F.** When the circuit is made the current flows, and the difference of potential is maintained by the consumption of the zinc. The electric current possesses energy and can therefore do work. The source of the energy is due to the action of the acid upon the zinc. In all cases of a current we must have one plate acted upon and gradually destroyed by a liquid; if both *A* and *B* were unaffected by the acid, it would be impossible to maintain an electric current.

For convenience we speak of the direction of the current

as being from a higher to a lower potential, that is the direction of the transfer of the positive electrification.

Fit up a simple cell (fig. 200), connect the wires called terminals, and observe the decomposition of the pure zinc. If ordinary zinc be used, action begins before the terminals are joined ; on joining the action increases. Collect the gas evolved ; it burns and can be shown to be hydrogen. Evaporate part of the liquid ; a white salt, called sulphate of zinc, remains. Notice that the temperature of the liquid rises.

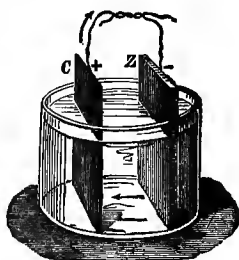


FIG. 200.

Polarisation.—Many of the very small bubbles of hydrogen adhere to the copper plate ; they reduce the available part of the copper plate, and thus oppose the current. Hydrogen just formed, is easily oxidized like zinc ; there is thus a tendency to send a current from the hydrogen to the zinc, this opposes the original current and ultimately equals it ; the action of the cell then ceases, and the cell is said to be polarised.

To prevent Polarisation.—(1) The copper plate may be frequently brushed ; the bubbles are thus removed, and the weakened current increases in strength. (2) The copper plate, or the plate that takes its place, may be roughened ; the bubbles form at the roughened points, enlarge, and rise to the top. (3) Chemical means may be adopted for removing the hydrogen or for preventing its formation.

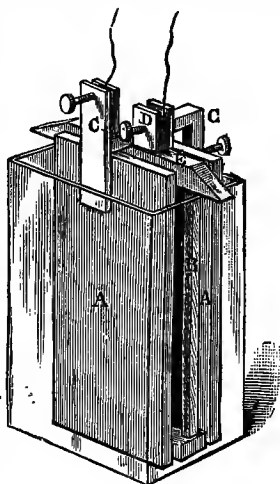


FIG. 201.

The Smee cell.—A thin plate of silver or platinum is covered with finely divided platinum, and is fixed in a framework, B (fig. 201), supported by a crosspiece, E ; a piece of copper wire is attached to the plate by a binding-screw, D. The zinc plates, A

are fastened together by a metal binding-screw, C ; to this screw is attached a copper wire.

The copper wire attached to the zinc is at negative potential, while that attached to the platinised plate is at positive potential. The electromotive force produced tends to send a current from the platinum terminal to the zinc terminal ; and if the poles be joined by a copper wire, a current flows. A Smee cell soon decreases in strength.

The Bichromate cell.—Certain substances, such as nitric acid and bichromate of potash, oxidise the hydrogen just when it is formed ; the hydrogen joins with the oxygen of these substances and forms water.

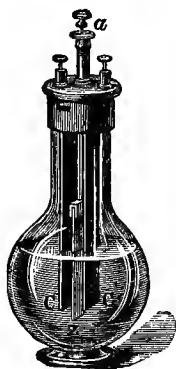


FIG. 202.

The bichromate cell consists of two plates of carbon, CC (fig. 202), connected by a metallic plate at the top, so that they practically form one plate. A zinc plate, Z, is between them. The liquid is bichromate of potash and sulphuric acid.

The solution attacks zinc, even when the circuit is broken ; the zinc plate is, therefore, always lifted out by the movable rod, *a*, when the circuit is broken. This cell is exceedingly useful, it acts well for short periods, and gives off no obnoxious fumes.

The Daniell cell.—In this cell, named after its inventor, the polarisation is prevented on a different principle. The plates are zinc and copper, but they are placed in different liquids, the zinc being surrounded by dilute sulphuric acid, and the copper by a copper sulphate solution ; the liquids are separated by a porous partition of unglazed ware. When the terminals are joined, the zinc is eaten away, forming zinc sulphate, and hydrogen is liberated ; the hydrogen does not escape at the zinc, it seems to attack the next molecule of sulphuric acid or hydrogen sulphate, and liberate the hydrogen of that molecule ; this in turn attacks the next molecule, and so on, until the porous cell is reached. The cell prevents the

liquids mixing, but does not prevent the passage of the hydrogen just formed; the hydrogen attacks the nearest molecule of copper sulphate and forms sulphuric acid and copper. The liberated copper attacks the next molecule of copper sulphate and liberates copper, and so on until the copper plate is reached; the last particle of copper from the last molecule of copper sulphate is deposited upon the copper plate, which is thus kept clean and there is no polarisation.

Copper is represented symbolically by Cu, zinc by Zn, sulphur by S, and oxygen by O. CuSO_4 is copper sulphate; ZnSO_4 , zinc sulphate; H_2SO_4 , hydrogen sulphate or sulphuric acid. The upper line (fig. 203) represents the position of the molecules before the circuit is made, the lower when action begins. P is the porous cell. The student should remember that these

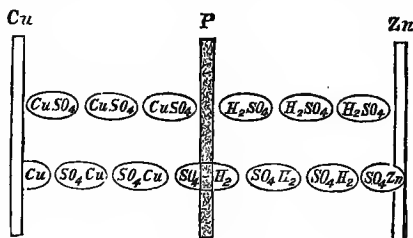


FIG. 203.

molecular changes cannot be observed; the diagram is merely to assist him in understanding what in all probability takes place.

The cells are usually constructed so that the copper plate, A, forms the vessel (fig. 204). The porous vessel, B, is placed in this

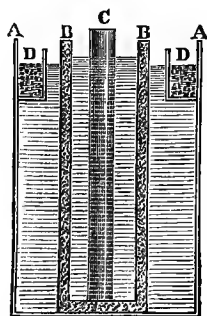


FIG. 204.

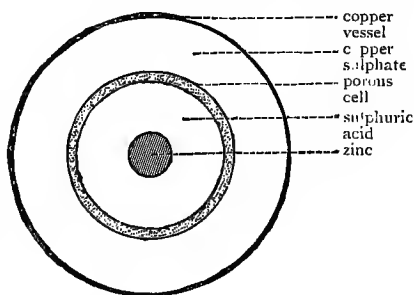


FIG. 205.

and the zinc, C, is placed inside the porous vessel. Inside the copper vessel is placed the solution of copper sulphate, with more crystals in a perforated trough, D, to supply the waste caused by the de-

composition of the copper sulphate. Dilute sulphuric acid (1 part of acid to 12 of water by volume) is poured into B. A plan of Daniell's cell is given in fig. 205.

The battery is very constant and no obnoxious vapours are given off. The porous cell becomes ultimately filled with a solution of zinc sulphate ; provided it does not become over-saturated, so that crystals are deposited, the zinc sulphate acts effectively instead of sulphuric acid.

The Grove cell.—The outer vessel, A (fig. 206), is of glazed porcelain ; C is a rectangular porous cell containing a plate of platinum, D. Around C is bent a plate of amalgamated zinc, B. The liquid in C is fuming nitric acid, and in A, dilute sulphuric acid.

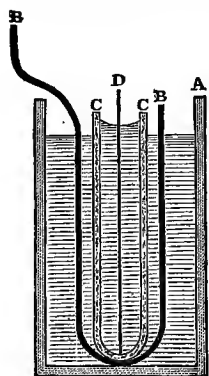


FIG. 206.

When the circuit is closed, a current passes from the zinc, through the sulphuric acid, liberating hydrogen ; this hydrogen passes the porous plate, and is oxidised by the nitric acid. The nitric acid is reduced to a gas that fumes in air, but does not attach itself to the platinum, which is thus kept clean. The cell is powerful ; but it soon weakens, and it liberates poisonous nitric fumes.

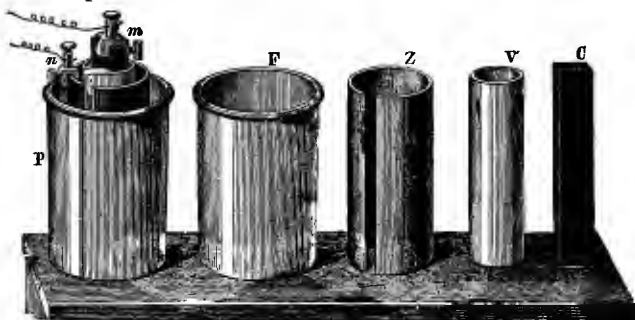


FIG. 207.

The Bunsen cell.—The construction and action are the same as the Grove, save that carbon takes the place of platinum.

The charcoal block, C (fig. 207), is placed in the porous cell, v, containing strong nitric acid ; v stands inside the divided cylinder of zinc, Z, which is placed in a glazed jar, F. The zinc is surrounded by dilute sulphuric acid. The terminals are connected to the zinc and carbon.

The Leclanché cell.—In a Leclanché cell, commonly used for electric bells, a block of carbon, C (fig. 208), stands in a mixture of the higher oxide of manganese (pyrolusite) and carbon, M, contained in a porous vessel, P. The porous cell is placed in a glass or earthenware jar containing a solution of sal ammoniac, the jar also contains a zinc rod, Z. The zinc dissolves, and the manganese is reduced to a lower oxide.

It acts well for a time, but it soon becomes polarised ; if allowed to rest, it regains its power, and, with frequent rests, acts for an almost unlimited time.

Amalgamation.—Impure zinc is readily attacked by dilute sulphuric acid, but the acid has no effect on pure zinc. Impure zinc contains particles of iron and other metals, and slight differences in composition cause difference in potential ; thus when a plate of ordinary zinc is placed in acid, currents called local currents ensue between various parts of the plate, the zinc is destroyed, without effectively aiding the current of the cell. To prevent local currents, the plates are amalgamated : the plate is dipped into dilute sulphuric acid ; when effervescence begins, it is removed, washed, and rubbed with mercury ; a uniform amalgam of zinc and mercury forms on the zinc ; this acts as the plate, and local currents are stopped.

A battery.—When two or more cells are joined together, so that the zinc of one is joined to the platinum, carbon, or copper

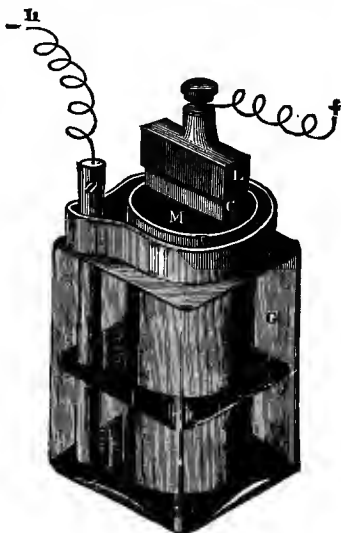


FIG. 208.

of the second by binding-screws *m* (fig. 209), the zinc of the second to the copper, &c., of the third, a battery is formed ; the terminals are joined to the zinc and copper of the end cells by

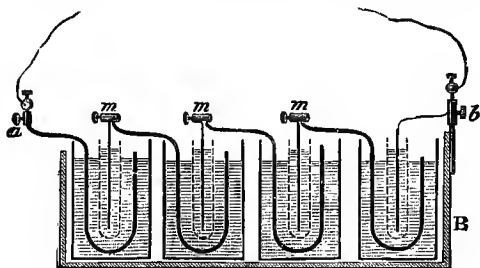


FIG. 209.

binding-screws, *a b*. Joining cells in this manner, is called joining 'in series.' Fig. 210 is the form of Daniell's battery

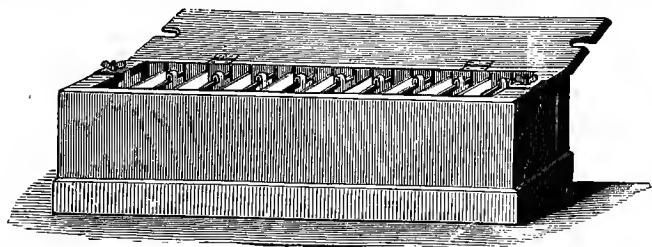


FIG. 210.

used in the Post Office. A teak trough is divided into ten cells by slate partitions, and the interior is coated with marine glue. Each cell is subdivided by a porous plate of unglazed porcelain.

EXAMPLES. I.

1. Explain the terms, a simple voltaic cell, and voltaic battery.
2. What is meant by electromotive force, and potential ?
3. How is the current sustained in a cell ?
4. What is meant by polarisation ? How is it prevented ?
5. Why and how are zinc plates amalgamated ?
6. Explain by the aid of a sketch, the construction of a Daniell cell.

CHAPTER II

THE CURRENT—THE GALVANOMETER

Effect of the current on a magnet. *Oersted's Experiment.*—Let a magnetic needle be suspended freely in the magnetic meridian. Above it, and parallel to it, hold a thick copper wire, joining

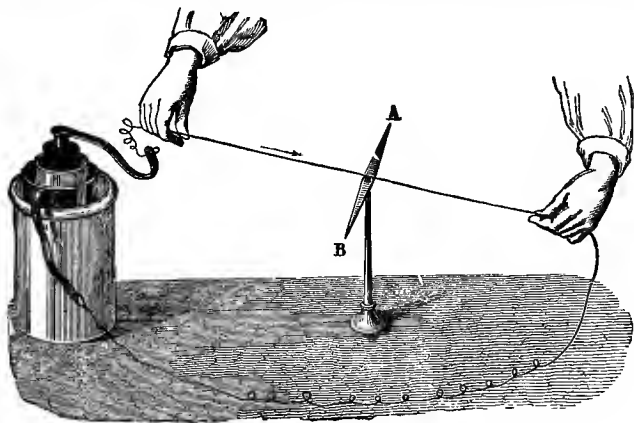


FIG. 211.

the poles of a cell. The needle is deflected. Now hold the wire beneath the needle; again deflection ensues, but in an opposite direction (fig. 211).

When the current flows from south to north, above the needle, the north-seeking pole turns to the west; when placed below, it turns to the east. If we hold the wire so that the current flows from north to south, the reverse effects are obtained. This relation between the current in the voltaic circuit and magnetism is very striking and important. There is evidently a magnetic field, surrounding the wire conveying the current.

The deflection of the needle is an easy method of detecting when and in what direction a current flows.

Ampère's rule for aiding the memory is : Imagine yourself swimming with the current, and *looking at* the magnet, so that the current enters your body at your feet and leaves it at your head ; the north-seeking pole will turn to your left hand.

The wire need not be exactly above or below, or parallel to the compass-needle. Hold the wire in various positions, and show that Ampère's rule meets every case.

The Multiplier.—If the current flow in one direction above the needle, and in the reverse direction below, both the current above and below, by Ampère's rule, tend to turn the north-seeking pole in the same direction ; the effect is greater than when

the single wire is used.

We can further increase the effect by making two, three, or more turns, and thus feeble currents are easily detected.

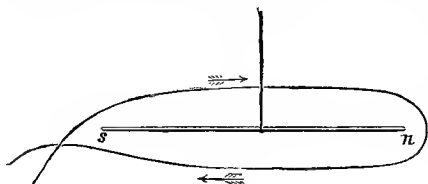


FIG. 212

Hold the wire above or below the needle, then turn the wire round the needle as in figure 212 ; note the increased effect ; turn it three or four times, and note further increased deviation.

Galvanoscope.—An instrument that detects electric currents, is called a galvanoscope.



FIG. 213.

A cheap galvanoscope.—Make a wooden framework 5" \times 1 $\frac{1}{2}$ " \times 1 $\frac{1}{2}$ " (fig. 213) with a groove an inch wide along the bottom. Wrap thick, covered wire ten or twelve times round, taking care that the wires neither touch nor cross each other. Attach the framework to a wooden board, A B (fig. 214), joining the terminals of the wire to the binding-screws B and C. Glue a graduated card, D, to the centre of the framework. A needle is fixed to a piece of wood glued to the centre of the card D, its point so placed that the compass resting upon it may be midway between the wires. Place the galvanoscope so that the needle is in the magnetic meridian.

The galvanoscope will detect a current if we join the terminals of a cell to the binding-screws ; and by applying Ampère's rule we can, by the motion of the compass, determine the direc-

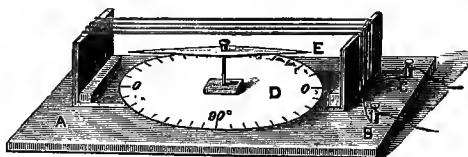


FIG. 214.

tion of the current. The galvanoscope is sometimes called a galvanometer ; the latter name should be retained for an instrument that *measures* a current.

The Astatic Galvanometer.—To detect feeble currents the astatic galvanometer is used. An *astatic needle* consists of two exactly equal magnetic needles, ab , $a'b'$ (fig. 215), attached to the same axis, their poles in opposite directions and both in the same vertical plane ; under the influence of the earth's magnetism such a needle would rest in any position ; a needle cannot, however, be constructed perfectly astatic. If the lower needle be surrounded by a coil of wire, mq , the action of the current both above and below will be to turn ab in the same direction ; no tends to set $a'b'$ also in this direction, while qp tends to set $a'b'$ in the opposite direction, but qp being further removed from $a'b'$ than no will have the less effect. The magnetism of the earth having such a small directive effect upon the needle, very feeble currents passing through the coil twist the needle.

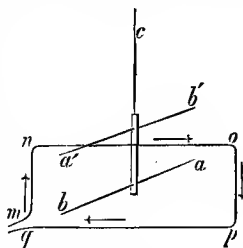


FIG. 215.

The coil consisting of many turns, as shown in fig. 216, the needle is suspended by a single fibre of unspun silk ; the wire forming the coil terminates in binding screws lo . The slit in the graduated circle c is parallel to the direction of the wires in the coil, and the zero of the card is at the continuation of this slit. To use the instrument, the frame carrying the coil is moved until the upper needle is at zero, the wires carrying the current to be tested are joined to lo . The instrument needs great care ; it will gene-

rally show a deflection from a battery made of a penny and an equal disc of zinc, separated by a piece of blotting paper dipped in brine. The needle, when not in use, should be lowered to rest on the card.

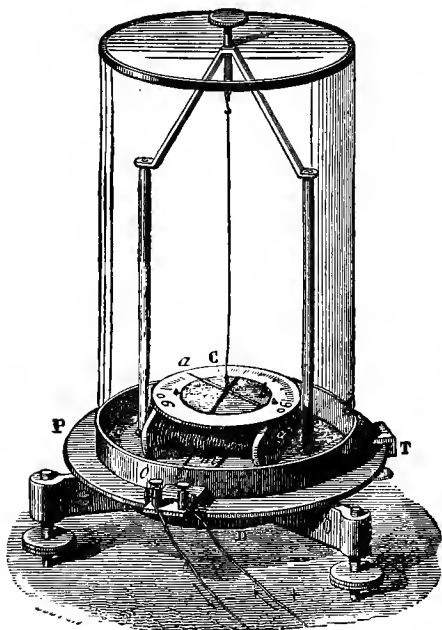


FIG. 216.

acid, showing in what direction the positive current passes through a wire connecting the two metals and also through the dilute sulphuric acid.

3. What are the materials used in the construction of a Daniell cell, and what chemical changes occur in the cell when in action?

4. Describe a Grove cell and explain its action.

5. Wires from two separate voltaic batteries are stretched one above the other from north to south (magnetic) and equal currents pass through both wires. If a magnetic needle, free to turn horizontally but not vertically, is hung half-way between the wires, how will it be effected (*a*) if the currents are both in the same direction? (*b*) if the currents are in opposite directions?

6. A wire lies east and west (magnetic) immediately over a compass needle. How is the direction in which the needle points affected when a strong current flows through the wire (1) from west to east: (2) from east to west?

EXAMPLES. II.

1. Two compass-needles are arranged near each other so that both point along the same straight line. A wire connecting the platinum and zinc ends of a battery is stretched vertically half way between the needles. How will the current in the wire affect the needles, and how will the result depend upon whether the platinum terminal is connected with the upper or lower end of the wire respectively?

2. Give a drawing of a galvanic cell of copper, zinc, and dilute sulphuric

7. If you have within reach two wires, connected one to one end and the other to the other end of a voltaic battery which is hidden, say how you could tell which wire is connected to the zinc end of the battery.

8. Describe an astatic galvanometer; why is the name not a good one?

Resistance.—The electric current produces a deflection of the simple magnetic needle or of the galvanometer needle. The stronger the current the greater is the deflection, although the deflection is not proportional to the strength of the current. The current is set in motion by the E.M.F.; if the E.M.F. be doubled or trebled, the current is doubled or trebled; it is proportional to the E.M.F. The strength of the current also depends upon the resistance it may have to overcome in the conductors: this is analogous to the fact that a current of water in a pipe depends not only upon the pressure, but also upon the size and interior condition of the pipe; if the pipe be partially filled with stones or sand, the flow is resisted and a smaller quantity of water passes per second.

Electrical resistance may be defined as that property of a conductor by virtue of which the conductor opposes the flow of an electrical current. The greater the resistance the less will be the strength of the current. The current is inversely proportional to the resistance.

The resistance of a conductor is inversely proportional to its cross section, a conductor whose section is 3 sq. inches has one-third the resistance of a wire of 1 inch section. The resistance is proportional to the length: other things being equal there is double the resistance in a telegraph wire 4 miles long that there is in one 2 miles long. The resistance also depends upon the substance of which the conductor is made; if we take the resistance of a good copper wire of given length and section as 1, the resistance of a similar iron wire will be about 6, of brass 4, of a similar length and section of mercury nearly 60.

The unit of RESISTANCE is called *an ohm*; it is nearly the resistance of a mile of pure copper wire whose diameter is $\frac{1}{4}$ inch, or of a tube full of mercury of the same section and $\frac{1}{60}$ mile or 88 yds. long. If the diameter of the tube be $\frac{1}{16}$ inch, the length of mercury will be 88 yards $\times 16 \div 100$, or

14.08 yards. To reduce the resistance we must either reduce the length or increase the cross section of a conductor.

The unit of ELECTROMOTIVE FORCE is called a *volt*, it is very nearly the E.M.F. of a Daniell cell. The E.M.F.'s of the other cells are roughly : Bunsen and Grove $1\frac{3}{4}$ to 2 volts, Smee $\frac{1}{2}$ volt, Bichromate 2 volt, and Leclanché $1\frac{1}{2}$ volt.

Ohm's Law.—The current strength is measured by the quantity of electricity that flows past any point of a circuit in one second. Both by experiment and calculation the following law has been proved true.

The STRENGTH OF A CURRENT is directly proportional to the ELECTROMOTIVE FORCE, and inversely proportional to the RESISTANCE of a circuit,

that is $\text{current} = \frac{\text{E.M.F.}}{R}$, if we use suitable units.

When the E.M.F. is *one volt*, and the resistance is *one ohm*, the current strength is called *one ampère*, the unit of current strength. When the current strength is *one ampère*, the unit of quantity of electricity flows past any point of the circuit in one second ; this unit is called *one coulomb*.

The total resistance of a circuit is not only the resistance of the wire joining the terminals, but also that of the cell or battery ; in fact the resistance of the battery, called the internal resistance, is frequently much greater than that of the outside resistance. The internal resistance depends greatly upon the liquid used ; we can reduce the resistance by enlarging the plates, that is, increasing the area of the cross section, or by bringing the plates closer to each other, that is, reducing the length of the liquid conductor. It is thus impossible to give exact value for the resistance of a particular cell ; the following may be used as applying to ordinary-sized cells :—Daniell 4 or 5 volts, Bunsen $1\frac{9}{10}$ volt, Grove $1\frac{9}{10}$ volt, Leclanché $1\frac{9}{10}$ volt, Bichromate $1\frac{1}{2}$ volt. The E.M.F. of a cell depends upon the materials of the cell and is thus the same for a large or for a small cell. The E.M.F. of a Daniell cell with plates 1 ft. sq. is the same as that of a cell with plates 1 inch square ; the larger cell has a smaller resistance and therefore produces a stronger current.

If we connect cells in series, (see p. 208), the total E.M.F. will be the sum of the E.M.F. of each cell. The current has to pass through each cell, and therefore the internal resistance will increase in the same ratio as the E.M.F. If two cells be placed side by side and the zincs connected with thick wire, and likewise the coppers, then practically one cell is formed with twice the size of plates (therefore half the resistance); if now terminals be attached to the thick copper wires joining the plates we have cells formed in *multiple arc*, the E.M.F. is simply that of one cell, the resistance is half that of one cell.

Example.—Find the current strength of a single cell, with an E.M.F. of 2 volts and a battery resistance of $\frac{1}{2}$ ohm, (a) when the outside circuit is a short thick wire (resistance practically 0), (b) when the outside circuit is 100 feet of No. 27 pure copper wire, whose resistance is 4 ohms. Find also the effect of two such cells, when joined in series and in multiple arc

(a) With short thick wire, total resistance (R) = $\frac{1}{2}$ ohm. E.M.F. (E) = 2 volts.

$$\text{Current from one cell} = \frac{E}{R} = 2 \div \frac{1}{2} \text{ amperes} = 4 \text{ amperes.}$$

(b) With long thin wire, total resistance = $\frac{1}{2} + 4$ ohms = $\frac{9}{2}$ ohms. E.M.F. = 2 volts.

$$\text{Current from one cell} = 2 \div \frac{9}{2} \text{ amperes} = \frac{4}{9} \text{ amperes.}$$

	Two cells			
	With small external resistance		With large external resistance	
	In series	In multiple arc	In series	In multiple arc
EMF in volts . . .	4	2	4	2
Battery R. in ohms .	1	$\frac{1}{4}$	1	$\frac{1}{4}$
External R. „ . . .	0	0	4	4
Total R. „ . . .	1	$\frac{1}{4}$	5	$\frac{17}{4}$
Current in Amperes .	$4 \div 1 = 4$	$2 \div \frac{1}{4} = 8$	$4 \div 5 = .8$	$2 \div \frac{17}{4} = .47$

The method of building up a battery for particular purposes will be best understood from working similar examples.

Heating effects of the current.—(1) *The conductor.* Connect the terminals of a Grove battery with thick copper wire; no effect apparently is observed. Divide the copper wire, and rejoin the ends by a piece of very thin iron wire.

The iron wire becomes red-hot, and may fuse. A piece of platinum wire shows a similar effect, but it is more difficult to fuse than iron ; this method was used in experiments to heat platinum wire, in order to show its expansion (p. 3). The thick copper wire is itself heated ; but the increase of temperature is so slight that it is not easily detected. The stronger the current, and the greater the resistance, the greater will be the heating effect.

(2) *The cell.* Not only are the conductors heated but the temperature of the cell rises.

When the current is opposed by the resistance, either of the external conductor, or of the battery, it loses energy that appears as heat ; the energy is not absolutely lost, but it ceases to be available for work by the current. Heat will appear where the resistance is greatest : if the terminals be joined by a short thick wire, most of the heat will appear in the battery, if by a long thin wire, then most of the heat will appear outside the battery.

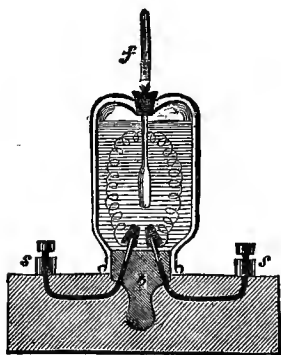


FIG. 217.

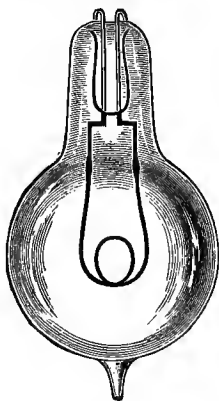


FIG. 218.

The heating effect may be used to raise the temperature of liquids.

A spiral of platinum wire surrounds a sensitive thermometer inserted in an inverted bottle ; the platinum is attached to thick copper wire, ending in *ss*. When *ss* are joined to a Grove cell, an increase of temperature is observed.

The Incandescent Lamp.—A twisted film of carbon attached to platinum wire is inserted in a small glass globe, and the air is exhausted. When the current from forty or fifty Grove cells is passed, the carbon is heated to incandescence; the resistance of such a lamp when incandescent varies, being from 100 to 200 ohms for ordinary sizes. The reason for the exhausting of the air is that the carbon may not join with the oxygen of the air and be destroyed.

In practice, the current is obtained from a dynamo machine.

EXAMPLES. III.

1. What do you mean by resistance? What is the unit of resistance?
2. Define electromotive force. What is the unit? What relation has it to difference of potential?
3. Write out Ohm's law. The terminals of two cells, each with an E.M.F. of $1\frac{1}{2}$ volts, and a resistance of $\frac{1}{4}$ ohm, are joined by a long wire with a resistance of 20 ohms. Find the current strength, when the cells are joined in series, and in multiple arc.
4. How is it that the poles of a battery are connected by a long thin wire and the battery does not get so hot as when a short thick wire is used.
5. A current flows through a copper wire, which is thicker at one end than at the other. If there is any difference either (1) in the strength of the current, or (2) in the temperature of the two ends of the wire, state how they differ from each other, and why.
6. Two Grove cells, alike in all respects except that in one the plates are twice as far apart as in the other, are arranged in series, and the poles of the battery so constituted are united by a copper wire. The liquid in both cells becomes heated. In which is the rise in temperature the greater, and why?
7. How could you boil water by means of the current from a voltaic battery? Give a sketch to explain the arrangement of apparatus you would use.
8. If a plate of copper and a plate of zinc connected by a wire are dipped into dilute sulphuric acid the connecting wire gets hotter when the plates are brought nearer together, and cooler if they are separated to a greater distance. Why is this?
9. A number of galvanic cells are connected together in a row so as to form a battery. This row is laid on a table so as to lie N. and S. The zinc is to the N. The poles of the battery are connected together by a wire, which passes from one pole, up one wall of a room, across the ceiling and down the opposite wall to the other pole of the battery. How will a magnetic needle be affected which is placed under the table and just below the battery?

CHAPTER III

ELECTROLYSIS—ELECTRO-MAGNETS

Electrolysis.—Many liquids and fused salts suffer chemical decomposition when a current passes through them. *Terms used.*—The liquid is generally in a vessel and is called the

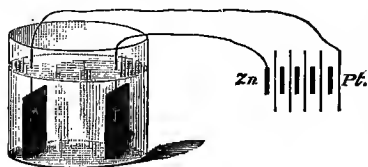


FIG. 219.

electrolyte. The current flows from the zinc to the platinum or copper in the battery, by the wire to A (fig. 219) through the liquid, and so on to the zinc. The solid conductor A, from which the current

enters the electrolyte, is called the *positive electrode* or *anode*, the solid conductor, B, into which the current flows, is called the *negative electrode* or *kathode*. The substances which appear at the electrodes are called *ions*: that at A the *anion*, at B the *kation*.

If the poles from a voltaic battery or cell be dipped into pure water, scarcely any effect is observable; the current is unable to pass through the water on account of its great resistance, similarly it is unable to flow through the air between the terminals. If now the water be slightly acidulated, a distinct change ensues; the addition of the acid has made it a conductor of the current. The battery begins to work, and if the E.M.F. be strong enough bubbles of gas rise from the poles. The water is decomposed.

In order to examine the ions, we collect the gases that collect at each electrode. The following is a convenient arrangement:—

Two pieces of glass tube are drawn out and platinum wires inserted (p. 15). The glass is melted and closes upon the platinum wire, the tubes are then bent as in fig. 220. Strips of platinum are placed upon a brick, a wire is placed upon each, both intensely heated with a Bunsen flame, and then smartly tapped with a hammer; the wire and foil are thus welded.

Pour mercury into the open ends of the tube; then arrange as in fig. 220, and dip the terminals from a good Grove cell into the mercury. Invert a test-tube full of water over each.

(1) From the positive electrode, half the amount of gas collects that appears at the negative electrode. If a glowing chip be placed in this gas, it bursts into flame; the gas is oxygen.

(2) The gas from the negative electrode is hydrogen; it burns with a colourless flame, and will not support combustion.

We learn by synthesis, that water is composed of oxygen and hydrogen in the proportion of one to two by volume. We verify this by mixing the gases in this proportion, exploding them and obtaining water-vapour, which condenses to a few drops of water.

Electrolysis of metallic salts in solution.—*Sulphate of copper.* Dip two platinum electrodes, A B (fig. 219), of a battery into a solution of copper sulphate. The negative electrode is soon covered with red copper, while a gas, found to be oxygen, rises from the positive electrode.

Copper sulphate consists of copper, sulphur, and oxygen. The copper is deposited, and sulphur and oxygen in combination left free. They join with the water, forming sulphuric acid, and an excess of oxygen, that appears at the positive electrode.

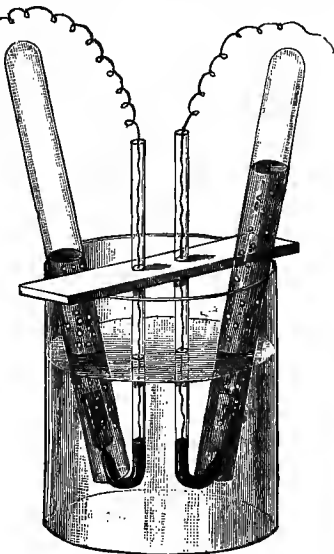


FIG. 220.

Wash the electrode covered with copper in water ; then boil in dilute nitric acid ; the copper will dissolve and leave the plate clean.

Acetate of lead (sugar of lead).—Lead, the metal, is deposited upon the negative electrode, while oxygen is liberated at the positive. The lead filament bridges between the electrodes, and then the electrolytic action ceases. Use lead electrodes, A B (fig. 221).

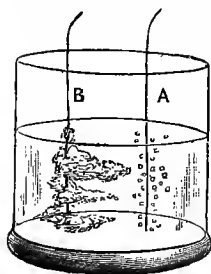


FIG. 221.

Nitrate of silver.—If nitrate of silver be similarly treated, silver is deposited upon the negative electrode, and oxygen is liberated at the positive electrode.

Sulphate of iron and other salts may also be used for experimental purposes ; in all cases the metal (in case of acids the hydrogen) is deposited or liberated at the negative electrode.

The elements given off at the positive electrode are called electro-negative elements ; those from the negative electrode are called electro-positive elements.

In the following table the common elements are arranged, beginning at the most electro-negative :

Oxygen	Gold	Lead
Sulphur	Platinum	Iron
Chlorine	Mercury	Zinc
Phosphorus	Silver	Sodium
Carbon	Copper	Potassium
Hydrogen	Tin	

The salts of the most electro-negative elements, potassium and sodium, act differently : the metal does not appear on the electrode, it combines with water, forms an alkali, and hydrogen is liberated.

Electro-chemical equivalent.—A strong current after decomposing water, as in fig. 220, might pass in turn through a solution of the various salts. The amount of the *ions* can be collected and weighed. If 2 grams of hydrogen be liberated, 16 grams of oxygen will be liberated, 63 grams of copper, 207

grams of lead, and 216 grams of silver. To effect the deposition of each of these amounts of the metals, 65 grams of zinc will be consumed in the battery. These numbers are in the same ratio as the chemical equivalents of the metals.

Electroplating.—In the electrolysis of the metallic salts examined, it is evident that the solution ultimately is weakened when platinum electrodes are used ; thus, in the case of copper sulphate, the copper deposits on the negative electrode, while the solution becomes a mixture of sulphuric acid and copper sulphate. By making the positive electrode of copper instead of platinum, the strength is kept constant. The copper is gradually eaten away, and the negative electrode with any suitable conductor becomes covered with a film of the metal. Advantage is taken of this in electrotyping and electroplating.

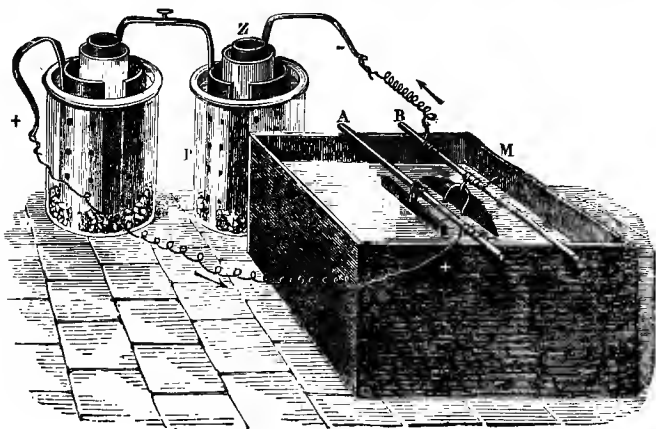


FIG. 222.

The commonest form is to cover white metal or German silver with a covering of silver. The article (say a silver fork) is thoroughly cleaned, to remove fatty matter and dirt. It is attached to the negative electrode of a battery, the electrolyte being a solution of silver, generally cyanide of silver. The positive electrode is a piece of silver, that is gradually eaten away, and serves a similar purpose as the copper plate (fig. 222).

Electrotyping.—A mould of the object (say a coin) is taken in

guttapercha or plaster of Paris, both non-conducting substances. To

make the surfaces conductors, they are brushed carefully with graphite (fig. 223). The mould is then attached to the zinc end of a voltaic cell, a copper plate being attached to the copper plate of the cell. The copper plate and the mould are placed in a solution of copper sulphate. The mould becomes covered with a coating of copper ; when suffi-

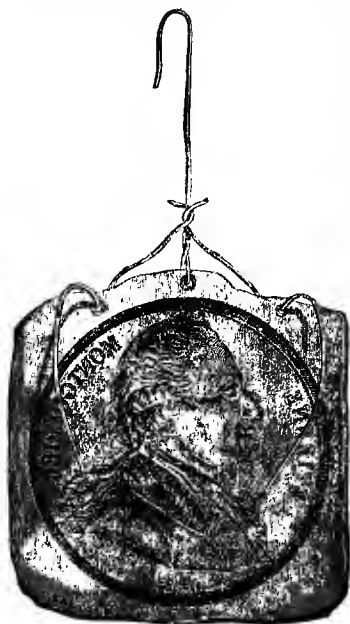


FIG. 223

ciently thick the mould is removed, and a casting taken in type-metal.

EXAMPLES. IV.

1. Describe some experiment to prove that when the terminals of a voltaic battery are connected by a wire, the battery itself is traversed by an electric current.

2. You have access to the terminal wires made of copper of a hidden battery. Explain how you would tell which wire was connected with the zinc and which with the platinum pole of the battery, by observing what happens when the ends of the wires are dipped at the same time into a solution of copper sulphate.

3. How would you arrange an experiment for the decomposition of water by an electric current? Give a sketch of the arrangement, and show where the different components of the water would be separated.

4. A piece of zinc and a piece of copper are each carefully weighed; they are then connected by a copper wire, and dipped side by side into dilute

sulphuric acid, contained in an earthenware jar. After, say, half an hour the pieces of zinc and copper are taken out, washed and dried and weighed again. Would the weights be the same as at first? if not, how, and why, would they differ?

5. A number of cells formed of plates of zinc and platinum immersed in dilute sulphuric acid, are to be connected in a circuit, so that the platinum of each cell is in contact with the zinc of the next. What effect, if any, would be produced on the current if, by mistake, one cell was made up with two platins instead of with one platinum and one zinc?

6. The current from a voltaic battery is passed at the same time through a thin wire and through dilute sulphuric acid, connected in series. What will happen to the wire, and to the dilute acid; and what change (if any) will be produced in each case, by reversing the battery connections, so as to alter the direction of the current through the wire and liquid?

7. What alteration is made in the current from a cell (1) by increasing the size of the plates, (2) by bringing them nearer together, (3) by shortening the connecting wire?

8. A piece of platinum is to be coated with copper by the help of a voltaic battery. Describe some arrangement that might be employed for this purpose.

9. Plates of copper and platinum are dipped into a solution of copper sulphate. What effects are produced upon them if a current is passed through the liquid from copper to platinum?

10. Two copper wires, one connected with one terminal of a voltaic battery and the other connected with the other terminal, dip side by side, but without touching each other, into a solution of sulphate of copper. What happens to the immersed part of each wire?

Telegraphy.—If the wire from a battery B (fig. 224), after traversing a distance, be doubled so as to surround a magnetic

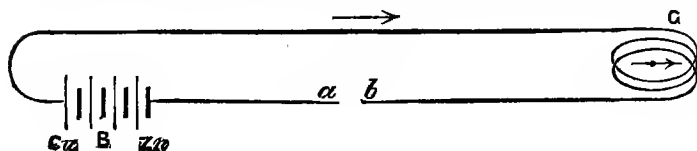


FIG. 224

needle and form a galvanoscope, then before the circuit is closed the needle will be at rest, being acted upon only by the earth's magnetism. The terminals *ab* will be at different potentials; on closing the circuit and breaking it at *ab*, the E.M.F. sends a temporary current flowing in the direction of the arrows;

the needle moves and its motion may be observed. This is the principle of telegraphy ; if the operator again joins *a b* another motion of the needle takes place.

It was soon found, that the return wire was unnecessary, the earth being a sufficiently good conductor for the return current ; thus the wire between *cu* and *G* might be removed, the ends being inserted in the earth. (See also fig. 227.)

For the purposes of signalling it is convenient to have the power of turning the needle either to the right or left—that is, it must be possible to cause the current to pass from the operative instrument, by the line to the receiving instrument and back by the earth, or to travel by earth and back through the line.

This reversal of the current is attained by the COMMUTATOR KEY (fig. 225).

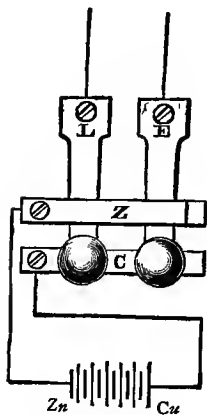


FIG. 225.

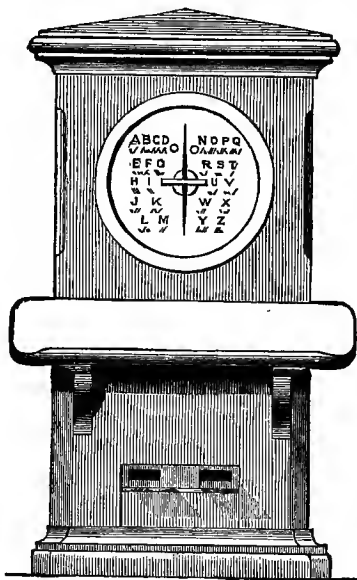


FIG. 226.

C and *Z* are strips of metal, connected respectively with the copper and zinc plates of a battery. *Z* is above *C* ; *E* and *L* are

two metallic springs called 'tappers,' fixed at E and L; they ordinarily press against Z. L is connected with the telegraph line, that passes round the galvanoscope; E is connected to earth; there being ordinarily no connection between Z and C, no current passes. If now the spring L be depressed, so as to make connection with C, the current flows from C, through L, and then to the galvanoscope, whose needle swings in one direction. If, on the contrary, E be depressed, the current flows by E to earth, to the galvanoscope, and back through the line to L; the needle then swings in the opposite direction. By noting the combination of right and left swings, the operator reads the message. (See alphabet fig. 226.)

The Single Needle Instrument.—A front view of the instrument is given; the tappers are seen in elevation (fig. 226). The steel indicator on the dial is parallel to, and moves upon the same axis as the magnet of the galvanometer, situated behind the dial.

A Telegraph circuit.—At each station (fig. 227), the zinc of the battery is connected with the galvanometer and also with

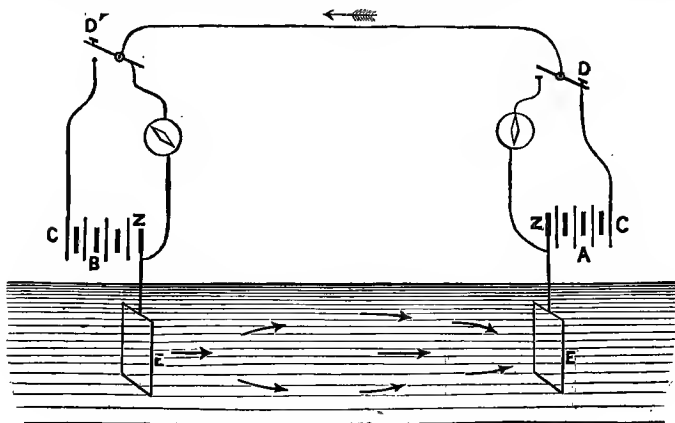


FIG. 27

the earth; the copper pole is joined to a free wire. Keys, D D' permanently connected with the telegraph line, can be joined at will, either with the instruments or with the free copper terminals; when no message passes they are connected with the

instrument as at D'. In order to send a signal, the operator at station A depresses his key D ; the current flows from z to c at A, along the line, through the receiving instrument at station B, to earth, and back to the battery at A. The clerk at station B reads from the receiving instrument. With the simple keys D and D' the needle would only swing to one side ; in the single needle instrument, D and D' are replaced by commutator-keys (fig. 225.)

Magnetic field due to a current.—Dip the wire through which a current is passing, into iron filings. The filings cling to it. When the circuit is broken the filings drop off (fig. 228).



FIG. 228.

The filings have been magnetised by induction. If we pass the wire through a hole in glass at right angles, and sprinkle iron filings upon the glass, the filings arrange themselves in circle ; they act as if they were in a magnetic field (fig. 229).

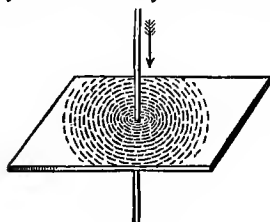


FIG. 229.

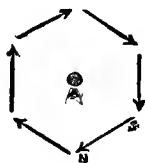


FIG. 230.

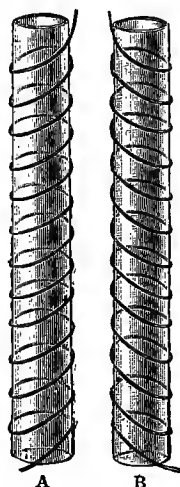


FIG. 231.

Imagine that a swimmer enters at A (fig. 230), dives into the hole in the direction of the current, and looks at each small magnet in turn ; then the north-seeking pole will always be at

his left hand ; the north-seeking pole is marked with an arrow. This is of course applying Ampère's rule (p. 210)

Spirals or Helixes.—A right-handed spiral or helix is formed by holding a tube upright, and coiling downward from right to left (A, fig. 231). In the left-hand spiral or helix the tube is held in a similar position, but the coiling is from left to right as you look at it, B.

Effect of the current on soft iron.—The inductive effect of a current acts also upon any mass of soft iron. Wrap copper-covered wire round a bar of soft iron (a poker) from end to end in a right-handed spiral. Attach the ends of the wire to the terminals of a battery. Hold nails or iron-filings to the ends of the bar, and prove that it is magnetised. Hold the compass-needle near each end ; one end is north-seeking, the other south-seeking. Mark them. Disconnect the battery ; the iron at once loses its magnetism

Notice where the current enters the helix ; imagine your man swimming with the current, then deduce which end should be the north-seeking pole of the soft iron. Reverse the battery connections. Now test the polarity of the bar ; it is reversed, but it agrees with Ampère's rule.

If after wrapping in a right-handed direction to one end, we return to the end first wrapped, still wrapping in a right-hand helix, we increase the effect of the current. If we wrap to one end in a right-hand helix, and then to the other end in a left-hand helix, we decrease the effect of the current.

An Electro-Magnet.—Bend a bar of soft iron in the form of a horse-shoe (or take a horse-shoe) and cover it with insulated wire. Remember to wind continuously in one kind of helix. Test the polarity of the electro-magnet ; notice its effect on nails held near it.

The soft iron is only magnetised as long as the current passes, reminding us of the magnetisation of a bar of soft iron by the induction of a magnet. The piece of soft iron placed across the ends is the armature ; it

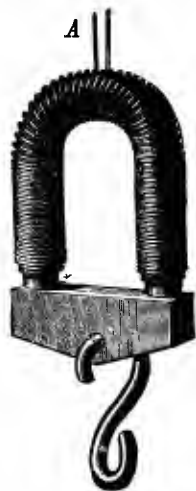


FIG. 232.

becomes magnetic by induction. The electro-magnet is able to support a considerable weight.

Use steel instead of soft iron ; the current must pass some time before good effects are obtained, but when the current ceases the steel retains its magnetism.

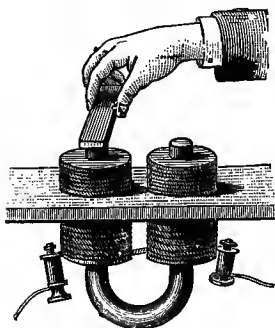


FIG. 233

An electric magnet forms an excellent means of magnetising magnets (fig. 233). It is only necessary to draw the bar of steel from one end to the other, repeating the operation several times on both sides. If we rub the north-seeking pole, the end of the steel last rubbed will be a south-seeking pole.

De La Rive's Floating Battery.—This battery illustrates the fact, that not only does a coiled wire through which a current

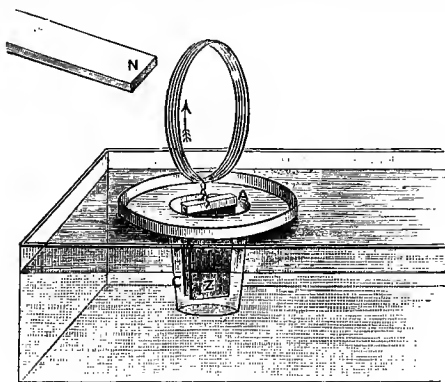


FIG. 234.

is flowing, magnetise a bar, but that it also acts itself as a magnet (fig. 234).

A beaker, C, is passed through a circular piece of wood, A. In the beaker are placed plates of zinc and copper attached to the sides of a crosspiece of wood. A coil of thick insulated wire is made

and the ends attached, one to the copper and one to the zinc. The beaker is nearly filled with dilute sulphuric acid, the current passed through the coil.

If we look at that end of the small coil, in which the current is flowing like the hands of a clock, that end will act like the south-seeking pole; this we may deduce by considering Ampère's rule. Present the south-seeking pole of a magnet to that end; the floating battery is repelled, and is attracted by the north-seeking pole.

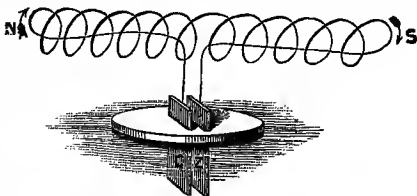


FIG. 235.

Wrap a covered copper wire into a helix, bring the ends round inside the helix to the middle. Fasten one end to a piece of zinc, the other to a piece of copper; pass both plates through a piece of cork. Float all in dilute sulphuric acid. Verify the names of the poles (fig. 235).

If the current be strong enough, the spiral will set in the magnetic meridian.

The Electric Bell.—The bell consists of a simple gong, T, and a horse-shoe-shaped bar of soft iron, round which is coiled insulated copper wire. The electro-magnet is retained in its place by the bar E. The armature of soft iron, *a*, carries the hammer, P. *a* is attached to its metallic support by a spring that keeps it pressed against another spring, C.

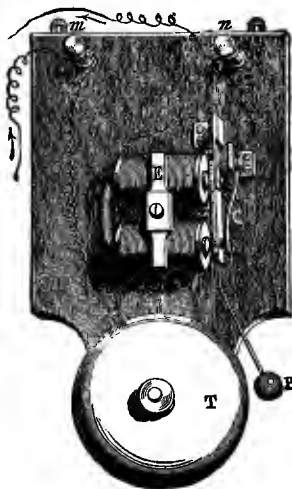


FIG. 236.

The current enters by the binding-screw *m*, and passes round the coils; it leaves the electro-magnet, proceeds to the metallic attachment of *a*, along *a* to the spring *c*, thence to the binding-screw *n*, and on to the battery. The circuit is complete.

The current magnetises the electro-magnet; this attracts the armature *a*, causing the hammer to strike the bell. The connection between *a* and *c* is then broken, and the current ceases; the soft iron electro-magnet is no longer magnetised, and therefore ceases to attract *a*, which, on account of the action of the spring, returns to its normal position, and thus makes contact with *c* again; then the process is repeated.

A single Leclanché cell is sufficient for a small bell.

Frictional and Voltaic Electricity.—The same terms have been used in describing the two forms of electrification. They are one and the same kind of electrification; the student will have observed that they produce similar effects. The heating, magnetic, and electrolytic effects obtained from the voltaic battery, can in a less degree be obtained from frictional electricity.

I. HEATING EFFECT.—Press a small strip of tinfoil between two plates of glass, connect one end of the tinfoil to earth, and present the other to the prime conductor of a good frictional machine.

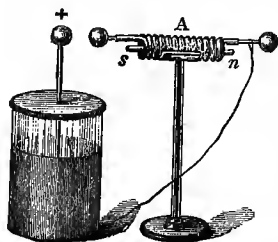


FIG. 237.

The current passes through the foil and fuses it.

2. MAGNETIC EFFECT.—Twist a piece of covered wire into a spiral *A* (fig. 237), rest it on a support and affix a knob to each end; insert a small needle *s n* in the spiral, connect one end of the spiral to the outer coating of a positively charged Leyden jar, and bring the other end to the knob; discharge the jar several times. The

needle becomes magnetised, the polarity being the same as would be produced by a current flowing in the direction of the discharge.

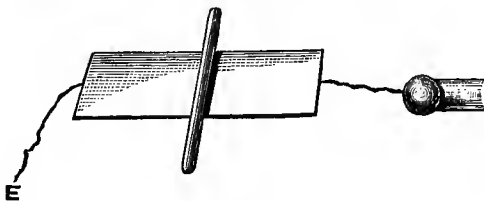


FIG. 238.

The same effect may be shown by insulating a piece of tinfoil

on a sheet of glass, and placing a needle across it (fig. 238); connect one end of the tinfoil to earth, the other to the prime conductor, and work the machine; the needle becomes magnetised; the near end being a S-seeking pole (see Ampère's Rule).

3. **ELECTROLYTIC EFFECT.**—Paste two pieces of tinfoil on a sheet of glass, about one inch apart; connect one to earth, the other to the prime conductor of a machine by a damp string. Midway between the pieces of foil place a drop of copper sulphate; bend two pieces of platinum wire, so that each will rest upon one piece of foil and dip into the copper sulphate. On working the machine, the piece connected to earth becomes coated with copper.

The electric discharges, accompanied by sparks, can also be obtained from the voltaic cell.

Wrap one terminal of a Grove, Bunsen, or Bichromate cell around a file, draw the other terminal along the file. Connection is rapidly made and broken, and a number of scintillations are seen.

The electricity from a frictional machine is at a high potential and can overcome the resistance offered by air, but the quantity produced is small. Faraday said that the amount of electricity in a lightning flash was less than the amount necessary to decompose a drop of water. The voltaic cell supplies a large quantity of electricity, but the difference of potential between the terminals is small, the current is therefore unable to overcome a great resistance such as air. Mr. De la Rue, by using 1,080 chloride of silver cells (E.M.F. slightly higher than a Daniell cell), could only obtain in air a spark of $\cdot 004$ inch; and with 11,000 such cells could only obtain a spark of six-tenths of an inch; it is only by using powerful batteries that Leyden jars can be charged; an ordinary cell has no appreciable effect upon a gold-leaf electroscope.

We may compare frictional electricity to a small quantity of water, raised considerably above the sea-level (high potential); it falls as a whole and produces striking effects but can do but little work. Current electricity we may compare to the current of water flowing from a large lake slightly raised above the sea-level; it can fill large cisterns and can do a large amount of work as it flows to the sea.

EXAMPLES. V.

1. How is it that iron filings sprinkled over a copper wire along which an electric current is passing stick to the wire?

2. What happens to a fixed bar of soft iron if the current from the platinum pole of a battery passes above it and at right angles to it?

3. A long copper wire covered with silk is wound several times round an iron rod. On connecting the ends of the wire one with each terminal of a Daniell's battery, the iron rod becomes a magnet. How does the direction of magnetisation of the iron (or position of its north- and south-seeking poles) depend upon how the copper wire is wound, and which end of it is connected with the copper end of the battery? Give a drawing.

4. A guttapercha-covered wire is wound round a wooden cylinder, A B, from A to B. How would you wind it back from B to A (1) so as to increase, (2) so as to diminish, the magnetic effects which it produces when a current is passed through? Illustrate your answer by a diagram drawn on the assumption that you are looking at the end, B.

5. An insulated copper wire is wound round a glass tube, A B, from end to end, and a current is sent through it, which to an observer looking at the end A appears to go round in the same direction as the hands of a watch. A rod of soft iron is held (1) inside the tube, (2) outside, but parallel to the tube. What will be the magnetic pole at that end of the bar which is nearest to the observer in each case?

6. Two copper wires connected, one with the zinc end and the other with the platinum end of a voltaic battery, but not connected with each other, are brought near a piece of sealing-wax that has been rubbed with flannel and then nicely balanced on a point. Would the wires differ in any way in their action on the sealing-wax? If so, how? and why?

7. A piece of copper wire is wrapped spirally round a ruler from end to end, and the ruler is hung horizontally so that it can turn about its centre while a current is passing through the wire. How can you tell, by using a bar magnet, in which direction the current is passing?

8. A piece of copper and a piece of zinc are put side by side into a vessel of dilute sulphuric acid. What takes place in the vessel when the copper and zinc are joined by a metal wire; and what new properties does the wire gain, different from what it had before?

9. Describe and explain any workable experiment to prove that the terminals of a galvanic battery differ electrically in the same way as the conductors and rubber of an electrical machine at work, but to a less extent.

EXAMINATION QUESTIONS



ALTERNATIVE ELEMENTARY PHYSICS

May, 1889

You are not permitted to attempt more than *eight* questions, and of these not more than *two* may be selected from any one subject

The value attached to each question is the same.

SOUND

1. A gun is fired on a cold winter's day at a certain distance from an observer, who hears the report five seconds after seeing the flash. Would the interval between seeing the flash and hearing the sound have been the same on a hot day in summer? Give reasons for your answer.

2. Describe an instrument by which the pitch of the notes emitted by two vibrating strings may be compared. If they were different, how would you attempt to bring them into unison?

LIGHT

3. What is meant by the law of inverse squares as applied to light? How is the law applied in comparing the intensities of two sources of light?

4. Describe and explain the difference of the effects observed when the sun sets over a smooth lake or sea, according as the water is (1) absolutely smooth, or (2) covered with ripples.

5. The shadow of a red-hot poker is cast on a white screen by means of a lime-light lantern. Explain the smoky appearance on the screen just above the shadow.

HEAT

6. To what reading on a Fahrenheit thermometer does 28° C. correspond? Why is it necessary to read the barometer when determining the boiling-point of a thermometer?

7. How is the climate of the British Isles affected by the high capacity for heat of water?

8. Two copper balls of the same weight, and raised to the same temperature, are laid, the one on a cake of slowly melting ice and the other on a cake of wax. The latter sinks in the more deeply. What inference would you draw from this?

MAGNETISM

9. A rod of iron and a rod of steel are stroked in succession with one of the poles of a bar magnet. How do the iron and steel rods respectively affect a compass needle when brought near to it?

10. How do (1) a dipping-needle, (2) a compass needle, behave at the magnetic poles of the earth?

FRICTIONAL ELECTRICITY

11. A certain substance becomes electrified when it is rubbed with a silk handkerchief. How would you determine whether its electrification is positive or negative?

12. A glass rod which has been rubbed with amalgamed silk is held near to an insulated metal ball, and the side of the ball nearest to the glass momentarily touched, after which the glass rod is removed. Describe and explain the effect of each step in the experiment.

13. Describe the construction of a simple form of electrical machine.

VOLTAIC ELECTRICITY

14. A vertical wire, down which an electric current is flowing, is held (1) due east, (2) due south of a small compass needle. How is the needle affected in each case?

15. A delicate thermometer is immersed in dilute acid into which plates of zinc and copper are dipped. When the plates are connected by a copper wire, the temperature of the liquid rises. Why is this?

16. Give a general explanation of the method of sending a telegraphic message.

APPENDIX



APPARATUS

THE following is a list of the apparatus and materials needed to perform the experiments in the work. The articles in lists A are those that will probably be obtained from instrument-makers; teachers with manipulative skill and time may reduce these lists considerably. They are recommended to obtain *Outline of Experiments and Description of Apparatus and Material* prepared by the late Professor Guthrie, F.R.S., issued by the Science and Art Department; this valuable pamphlet has been frequently used in this work. The construction of the apparatus in lists B is described in the work. Details of lists C follow. The figures in brackets refer to the pages. Articles marked with an asterisk may be dispensed with in an Elementary course.

HEAT

A

Cryophorus:	Set of cylinders (64). Copper, tin, lead, iron, zinc, cork and wood.
Thermometers:	1 lb. thermometer tubing.
1 Centigrade, to 100° and 200°.	1 lb. barometer tubing.
1 Fahrenheit, to 212°.	Rods of brass, iron, &c., 18 in.
Contraction apparatus (14).	Bell-jar, with stopper.
2 concave tin reflectors (50, 70).	

B

Differential thermometer (21), unequal expansion bar (15), apparatus to show expansion of metals (3), Gravesande's ring (4).

SOUND

A

- | | |
|---|--|
| * Air-pump. | Thin deal board, 24 ins. sq. (c). |
| * Alarum (2) (a). | Hand-bell (d). |
| Indiarubber tubing, 12 ft. | 12 Solitaire balls. |
| One tuning-fork. | (a) Use common alarum clock. |
| Violin bow. | (b) Cover with list, suspend by threads, and use for sounding-board. |
| 2 tin tubes, each 3 ft. \times 4 in. | (c) Use for sounding-board. |
| Gas cylinder, 12 in. | (d) Use stoppered bell-jar ('Heat'). |
| Strong globular flask (57). | |
| Whistle. | |
| Deal rod, 12 ft. by 1 in. by $\frac{1}{2}$ in. (b). | |

C

(a) Savart's toothed wheel (74); (b) siren (74); (c) humming-top fitted with Savart's wheel; (d) monochord; (e) square of glass (56); (f) set of weights, three of 1 lb., two of 2 lbs., one of 5 lbs., three of 10 lbs., one of 20 lbs.

(a) *Savart's Wheel*.—A thin sheet-iron wheel of 24 centimetres diameter; divide the circumference into 24 parts; notch in each part six teeth.

(b) *Siren*.—A thin sheet of good, smooth, stiff cardboard (fig. 239). From the centre *c* draw circles having the following radii: 8.5, 9.5, 10.5, 11.5, and 12 centimetres. By geometrical means draw diameters *ab*, *cd*; then obtain the points *f*, *g*, *h*, *i*; join the opposite points; the circle is now divided into twelve parts; divide each part of the circle having the radius 9.5 centimetres into five parts. Bisect each twelfth part, and draw the radii; now bisect each part of inner circle, trisect the parts of the third circle, and divide the parts of the outer circle into four parts. Indicate the points carefully, and have the holes punched by a saddler. The first three circles of holes will be sufficient for ordinary experiments. These sizes are for use with the whirling-table, one half-size for top.

(c) Fill a large humming-top with sand, seal the hole, then drive a small smooth-headed nail into the peg. Cut the upper stem so that the section is that of an equilateral triangle. Now puncture holes corresponding with this section in the centre of the wheels. Fasten the wheels to the top by means of washers with triangular apertures. Spin on the bottom of a tumbler.

If possible obtain a whirling-table (fig. 240); the action is more under control. An old foot or hand sewing-machine, with the body removed, when adapted to receive the wheels, would suit admirably.

(d) *Sonometer, Monochord*.—An inch deal board, 3 feet long, 9 inches wide; two pieces of wood 6 inches \times 1 inch \times 1 inch, screwed on across

ends of board, to form supports. Three long wooden screws driven in obliquely (slanting outwards) at one end at equal distances. At the other

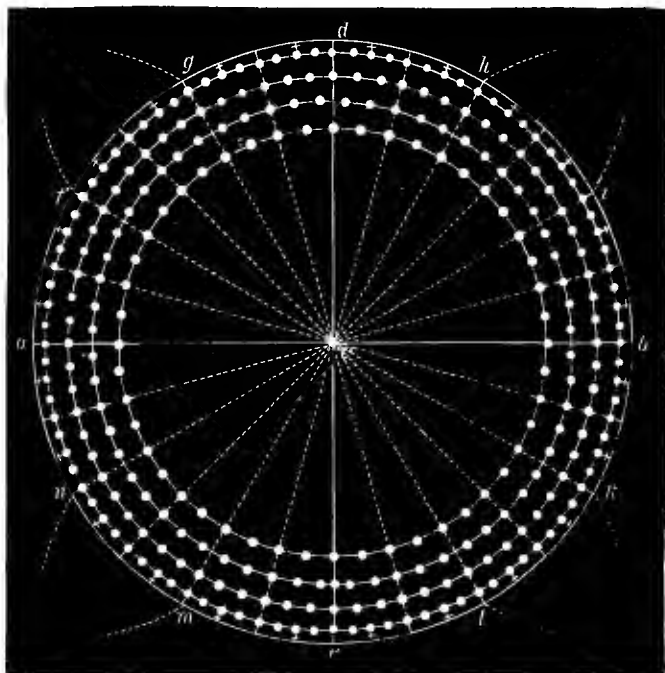


FIG. 239.

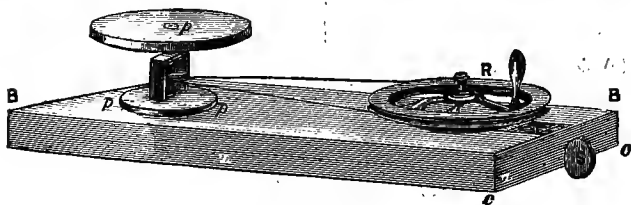


FIG. 240.

end opposite one screw is a pianoforte peg at an angle of 45° . Opposite the other two screws are two brass pulleys (window-blind pulleys) on stems

which are driven in at an angle of 45° . A bridge—that is, a triangular wedge of hard wood—9 inches long, $\frac{1}{4}$ inch wide at base, and as high as the pulleys. This is screwed from below across the board, about 3 inches from the wooden screws. Three other little movable bridges about 1 inch long, as high as the pulleys, are provided. A variety of weights and hooks; a pair of pliers; several yards of iron wire (pianoforte wires) of different thicknesses; brass wire, some of which has the same thickness as some of the iron wire. The ends of three pieces of wire are twisted into loops and passed over the screw-heads. One of the other ends is passed through the pianoforte peg, which is then twisted round by the pliers. The other two have loops twisted in them, and, passing over the pulleys, carry the weights.

A sheet of paper is gummed to the board, having lines at every inch and thinner ones at every $\frac{1}{16}$ inch. Mark with o the line beneath the pulleys and at the pianoforte peg.—*Molecular Physics*, F. Guthrie.

(e) A square of strong window glass, 9 ins. side; file the edges and smooth on a stone.

(f) Buy $\frac{1}{2}$ cwt. of scrap-lead. Melt a little over 10 lbs. in a ladle; remove the scum; make a cylindrical hole 4 inches diameter, in moist clay, with a wooden cylinder. Into the middle of the base insert a stout iron wire so that 2 inches are in the clay. Pour in the lead. When cold bend the wire to form a hook at each end. Correct the weight with standard weights; file off the necessary amounts. Similarly make the others.

LIGHT

A

Lantern (a).

1 concave mirror.

1 convex mirror.

2 flat glass cells.

Strips of thick plate glass.

Strips of crown glass.

Hand reading-glass.

Carbon disulphide prism.

Prisms, 2 equilateral.

Square of roughened glass.

Strips of coloured glass.

2 ground-glass globes.

2 sheets of looking-glass.

(a) A cheap lantern will answer as far as the spectrum and other experiments in this work are concerned. If the classes be held during the day, sunlight may be used.

B

Newton's colour disc (127).

| Refraction apparatus (110).

C

(a) Blackened glass. (b) Blackened paper. (c) Set of lenses. (d) Model of the eye.

(a) Warm the glass, rub with solid paraffin, remelt and drain off as much as possible ; light a piece of camphor, hold paraffined side in the smoke. Remove black with a needle.

(b) Dissolve as much shellac as possible in methylated alcohol ; allow the mixture to stand for 24 hours ; pour off ; add to solution as much again of alcohol ; add lampblack. Paint cardboard with this.

(c) A convex and a concave spectacle-glass will answer ; insert them in cork or cardboard frames fixed on thin wooden cylinders. Place cylinders vertically in wooden feet.

(d) Fig. 241 represents a wooden box 3" \times 3" \times 6", blackened inside, with the back B made of glass. A watch-glass (cornea) F is inserted in a

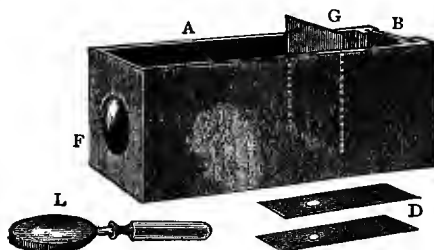


FIG. 241.

hole in front ; the crystalline lens is represented by a hand convex lens L, placed behind the cornea (see fig. 242, and compare fig. 112). Fill box with water, place in front of cornea a lighted candle, and obtain image on

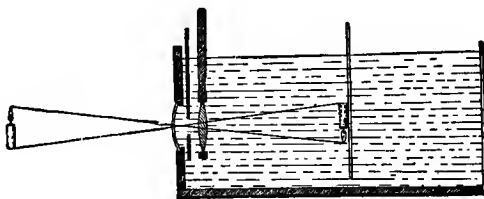


FIG. 242.

the roughened glass (the retina). One of the pieces of blackened tin, D, with circular aperture, represents the iris. Place concave and convex spectacle-glass in turn in front of cornea, and note how the position of roughened glass must be altered.

MAGNETISM

A

Piece of lodestone.	Bar of soft iron (a poker or ten-penny nail).
Pair of bar magnets.	Bar of steel.
Horse-shoe magnet.	Iron filings, nails, &c.
Knitting and sewing needles.	Untwisted silk (draw threads from a cheap ribbon).
Watch spring.	
Magnetic needle on stand (see list B).	

B

Magnetic needle on stand (133).	Dipping-needle (145).
Mariner's compass (151).	

FRICTIONAL ELECTRICITY

A

Cylinder machine (see C).	Stick of roll sulphur.
6 vulcanite stirring-rods.	Electrical amalgam.
Sheet of glass.	Sheets of thin and thick vulcanised indiarubber.
Tinfoil.	Small book of gold leaf.
Sheet of tin.	

B

Balanced rods (161, see also list C).	Discharger (197).
Balanced straw (162).	Proof-planes (174).
Electroscope (165, 166).	Leyden jar with movable coatings (197).
Leyden jar (194, 196).	Insulating stands (173).
Hollow vessel (fig. 178).	

C

Glass rod (<i>a</i>).	Electrophorus (190) (<i>e</i>).
Rod of sealing-wax (<i>b</i>).	Pith balls (<i>f</i>).
Varnish (<i>c</i>).	Cement (<i>g</i>).
Insulated conductors (figs. 173-5, 177, 180) (<i>d</i>).	Cylinder machine (<i>h</i>).
	Silk and flannel rubbers (<i>i</i>).

(*a*) Thoroughly clean and dry glass rod $\frac{1}{2}$ in. diameter, close and round one end in the Bunsen flame.

(*b*) Melt and fasten four ordinary sticks together, round the corners with a hot knife-blade.

(c) Half-fill pint bottle with shellac, cover the shellac with methylated spirits, shake frequently; varnish will be ready in about 24 hours.

(d) Obtain shapes in wood from a turner, cover with tinfoil, using good paste, smooth carefully the joinings. Mount on rods of varnished glass or on vulcanite stirring-rods. Brass balls 1 in. in diameter, that can be obtained from the dealers mounted on vulcanite stirring-rods, are also useful. Blown eggs carefully covered with tinfoil and suspended by dry silk threads answer equally well.

(e) 1. THE GENERATING PLATE.—A thick circular piece of vulcanised indiarubber 6 in. to 8 in. diameter is useful; frequently clean the surface with a little alcohol; the plate acts best when placed on a sheet of tin called the sole.

A sheet of vulcanite is excellent, but is dear. A mixture of 5 parts of shellac, 5 of gum mastic, 2 of Venetian turpentine, and 1 of marine glue melted in a pan and cast into a plate, may be used. The surface-bubbles may be broken by brushing over the plate with the flame of a Bunsen burner.

2. THE COVER.—A piece of tin or zinc, one inch less in diameter than the sole; the edge should be carefully turned up and rounded by a tinman; to the centre solder a small cylinder $\frac{3}{4}$ in. long, to contain the handle; fix the handle (a vulcanite stirring-rod) with cement.

(f) Pith balls. Pith of elder shaped into spheres. Small balls of cork answer well: suspend by cotton or silk threads according to experiment.

(g) Cement. 5 parts of black resin, 1 part of bees' wax, 1 part of red ochre, $\frac{1}{16}$ part plaster of Paris. Melt the resin in a vessel, add the wax, then stir in the plaster of Paris and colouring matter. Melt the cement before use and warm the objects before applying it.

(h) 1. THE CYLINDER.—Test several glass bottles by rubbing them on amalgamed silk, and noticing their electrical effect on pieces of paper; select the best. The bottle should have a deep cavity in the bottom. Fit an iron rod into a piece of wood that nearly fills the cavity; fix the wood with cement. The iron rod and the bottle-neck rest in the holes cut in the supports B B' (fig. 187). Cement an iron rod bent twice at right angles into the mouth of the bottle for a handle.

2. THE FRAMEWORK.—Make it of wood, size suitable for the bottle (fig. 187).

3. THE CUSHION.—Stuff a leather cushion with horsehair; cover the leather with silk. A string tied round the wooden support of E (fig. 187) near the top, brought under the bottle and attached to a screw-nail on the side of the base-board nearest to the prime conductor, will supply the means of arranging that the rubber presses against the cylinder; the silk flap F is attached to the silk on the rubber.

4. THE PRIME CONDUCTOR.—A wooden cylinder with rounded ends is covered with tinfoil; the points are pins with the heads taken off.

Rub amalgam on the rubber with a little lard.

(2) SILK.—Six 6-in. squares stitched together at edges with silk thread, improved with amalgam.

FLANNEL.—Four 6-in. squares of red.

VOLTAIC ELECTRICITY

A

Cells: * Smee's, Bichromate,	* Astatic galvanometer.
Daniell's, * Grove's, * Bunsen's.	Sheets of copper.
6 binding-screws.	Sheets of zinc.

A Grove or Bunsen may take the place of the Bichromate.

B

Galvanoscope (210).	Floating battery (228)
Electro-magnet (227, 229).	Electric bell (229). The descrip-
Apparatus for electrolysis (220)	tion and cut (fig. 236) should be
Commutator key (224).	sufficient.

TO USE A CELL OR BATTERY. (1) Carefully amalgamate the zinc plates (207). (2) See that all the connecting parts, the binding-screws, and the ends of wires are clean and bright; if necessary rub them with emery cloth; afterwards with a clean, dry cloth. (3) *Porous cells.* Dip open ends in melted paraffin; this prevents the acids creeping up the sides. (4) *To start the battery.* Make the connections. Pour strong nitric acid into the porous cell (of Grove or Bunsen) to about 1" of the top; pour sulphuric acid (1 to 12 by weight) into the outer cell, so that it stands a little higher than the nitric acid. For Bichromate battery the mixture is 50 grains of bichromate of potash, dissolved in $\frac{1}{2}$ litre of hot water; when cold add 30 cub. c. of strong sulphuric acid. (5) *To disconnect the battery.* Wash carefully the binding-screws, ends of wires, &c., brighten and dry perfectly. Pour nitric acid into large bottle; it may be used again if it be not of a green colour. Sulphuric acid should not be used again. Wash the porous cells and leave them to soak in water. Wash the zincs, re-amalgamate where necessary and leave them covered with water.

GENERAL APPARATUS

Balance, to carry 1 kilo.	1 Bunsen burner
Weights, 1 kilo. to 1 decigram.	1 spirit lamp.
One retort-stand with clamps.	1 dozen assorted test-tubes.
Iron tripod.	Set of 6 beakers.

1 dozen assorted flasks :	2 ft. indiarubber tubing ($\frac{3}{8}$ in.).
4 of 2 oz., 2 of 4 oz., 2 of 6 oz.,	Tinfoil.
2 of 8 oz., 1 of 12 oz., 1 of	1 sq. ft. iron gauze, coarse.
16 oz.	„ „ fine.
3 indiarubber corks.	Copper wire covered with cotton.
Glass funnel.	„ „ silk.
3 dozen ordinary corks.	Iron and copper wire, 18 in.
Cork-borers, small set.	1 sq. ft. iron plate
3 lbs. glass tubing (assorted).	2 sq. ft. tin plate.
$\frac{1}{8}$ lb. glass rod.	Metre scale.
Platinum wire, 8 in.	Retort, stoppered

CHEMICALS

Ether, meth., 2 oz.	Silver nitrate, 2 drams.
Turpentine, 2 oz.	Paris plaster.
Alcohol, meth., 1 pint.	Hydrochloric acid, 1 pint.
Carbon disulphide, pure, 4 oz.	Sodium sulphate, 1 lb.
Sulphuric acid, 1 pint.	Tincture of iodine, $\frac{1}{2}$ oz.
Nitric acid, 1 pint.	Sulphur, 1 lb.
Beeswax.	Resin.
Solid paraffin.	Calcium chloride, $\frac{1}{2}$ lb.
Copper sulphate, $\frac{1}{4}$ lb.	Mercury, 5 lbs.
Lead acetate, 1 oz.	Lampblack.

ANSWERS

HEAT

- II. (3) 88.8°C . (4) 30. (5) F° 122, 50. 19.4, 356, 90.5 . (6) C° 32.2 , -1.1 , -26.1 , 0, 82.2 .
- III. (6) F° 59, 86, 63.5 , 32, 212, -22 , 14; C° 82.2 , 100, 21.1 , 15.5 , -24.4 .
- IV. (1) *a.* .00001875. *b.* .000008. (2) .0432" too long. (3) 352 yds. (rails of cast iron).
- V. (2) 120.306 cub. in. (5) 20.054 cub. in. (6) 1".
- VII. (3) 1172 cub. ft., 1492 cub. ft., 1012 cub. ft.
- VIII. (2) 4.5°C . (3) $33\frac{8}{14}^{\circ}\text{C}$. (4) 60, 5. (7) 44.8°C . (8) 96.8°C (9) 55.5 . (10) 90.9°C . (11) .095, 4.75 . (12) .0974.
- IX. (2) 5.7°C . (3) 115°C . (9) 40 min. (13) .092.
- X. (8) 536.7. (13) 6.3°C . (14) 1.25 lbs.

SOUND

- I. (6) 2240 yds.
- II. (6) 20 ft. (14) (a) 4 ft. (b) $2\frac{6}{11}$ ft. (15) 1200 ft. per second.
- III. (1) 40. (4) 1120×15 ft. per sec. (6) Intens. at 1100 : intens. at 1800 :: 324 : 121.
- IV. (3) 36.3 .
- V. (1) 426.6. (2) 4 lbs. (4) 80 lbs. (6) Vibration numbers become 1,200, 100; 800, $133\frac{1}{3}$. (7) $28\frac{2}{3}$ sec., if the temperature of the air be 15°C . Temperature omitted

LIGHT

- I. (10) 144 sq. in.
- II. (3) 10 ft. (5) Circle $4\frac{2}{3}$ " diameter.
- IV. (3) $f = 10$ ". (4) $f = 20.9$ ", $r = 41.8$ ". (5) (a) 9", (b) 30" behind the mirror, a virtual image. (10) for real image, more than 12" distant, for virtual image less than 12" distant.

VOLTAIC ELECTRICITY

- III. (3) In series $\frac{6}{41}$ ampère, in multiple arc $\frac{12}{101}$ ampère.

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